# DATA BOOK FOR ENVIRONMENTAL TESTING AND SPACECRAFT EVALUATION

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Prepared By
**TEST AND EVALUATION DIVISION**

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# PREFACE

The purpose of this data book is to keep Test and Evaluation Division engineers abreast of pertinent current developments in NASA programs and provide an up-to-date reference book for environmental testing and spacecraft evaluation.

## VOLUME 1

Sections I and II present the current status of Goddard satellite and NASA launch vehicle and sounding rocket programs.

Section III summarizes currently effective levels for Goddard environmental testing of Spacecraft and sounding rockets. This Section also contains a bibliography of reports on past and current Goddard environmental test programs.

## VOLUME 2

Sections IV and V summarize scientific and engineering data on the space and launch environments, respectively, which Goddard spacecraft encounter. Section VI will summarize data on the pre-launch environment when completed.

As the NASA Environmental Design Criteria documents now under preparation at various NASA centers are completed and approved, Section IV will be revised as indicated by the contents of these papers. Preparation of Section VI likewise will take advantage of these documents.

Appendix A is a glossary containing definitions of common space terms as well as definitions which particularly apply to environmental test and evaluation activities. It has the specific purpose of providing standardized definitions for terms commonly used in reports and specifications which originate in the Test and Evaluation Division.

Appendix B consists of an international log of space launches which contains key data on all launches since the first Soviet shot on October 4, 1957.

# CONTENTS

# SECTION IV

# THE SPACE ENVIRONMENT

# INTRODUCTION

The total environment in which the space vehicle must function includes the pre-launch, launch, and space environments. Section IV describes the space environment; and Sections V and VI, when completed, will present the launch and pre-launch environments.

Research for Section IV has included pertinent findings of scientific satellites, and the respective units describe different phenomena of space, based on available scientific data. For the contribution of their judgment and time in review of the various units of this Section, we are most grateful to R. E. Bourdeau, Dr. W. Nordberg, W. M. Alexander, Dr. C. E. Fichtel, H. H. Malitson, and Dr. J. P. Heppner, all of Goddard Space Flight Center.

Each unit deals with one aspect of space environment and contains a list of references in case the reader wishes to study the subject further. The units of Section IV also indicate some of the effects of particular phenomena of space on space vehicles. Brief abstracts of the material in Section IV appear below.

### *The Earth's Atmosphere*

The NASA-sponsored U. S. Standard Atmosphere, 1962 has furnished the major portion of the material for this unit. Marginal graphs show average values of atmospheric pressure, density, and kinetic temperature for all altitudes to 700 km. The paragraphs on atmospheric composition present the concentrations of both the neutral and ionized molecules. This unit concludes with probability contours for the extreme wind conditions over the United States, abstracted from design data recommendations in the U. S. Air Force Handbook of Geophysics.

### *The Structure of the Ionosphere*

Photoionization results in the formation of distinct regions of electron concentrations in the upper atmosphere which are known as the ionosphere. This unit describes the characteristics of these regions, including the numerous variations in electron densities as to time and what is known of causal and accompanying phenomena.

### *Solid Particles*

This unit describes the types of solid particles and their distribution in atmosphere and space. Recent satellite experiments and ground observations form the basis for current thought on this subject.

### *Energetic Particles*

This unit deals with the atomic and subatomic matter found in space. Although negligible in size, these particles have dangerously high energies. The introductory figure plots the flux of the various particles as a function of their energy. The major classifications--cosmic rays, particles of solar origin, and particles trapped near earth--are easily seen on this plot, as is the fact that particles of cosmic origin have the highest energies, while the trapped particles exhibit the greatest intensities.

### *Electromagnetic Radiation*

This phenomenon arises from two major sources: the sun and the earth. The unit incorporates recent data obtained by the Tiros satellites in a review of current knowledge.

### *Magnetic Fields*

This unit discusses the intensities and variations of the magnetic fields which exist at the surface of the earth, in the atmosphere, ionosphere, magnetosphere, and interplanetary space. Evidence from experiments carried by deep space probes forms the basis for estimates of the magnetic field strength in interplanetary space.

# EARTH'S ATMOSPHERE

The earth's atmosphere is a gaseous envelope surrounding the earth and extending outward to where the kinetic velocity of the atmospheric particles overcomes gravitational forces at distances from one-half to one earth radius from the earth's surface. At altitudes up to 90 km the atmosphere is a stable, homogeneous mixture, consisting mainly of nitrogen and oxygen molecules in the ratio of about 4 to 1. Above 90 km the diffusion process becomes more important than the mixing process, and the various atmospheric constituents tend to concentrate at various levels in atomic form with oxygen (having the highest atomic weight) concentrating at lower levels and the other elements tending to concentrate at successively higher levels in order of decreasing atomic weight. An added complexity in the atmospheric composition above 90 km results from the dissociation and ion production induced by solar radiation; below this altitude the atmosphere consists mainly of neutral molecules while at higher altitudes the concentration of ionized particles is significant.

Atmospheric parameters of major interest are the pressure, temperature, density, composition, and wind structure as a function of altitude. Up to 700 kilometers altitude, the best existent summary of pressure, temperature, and density, and variations therein (some estimated) is the 1962 version of the U. S. Standard Atmosphere. Temperature, pressure, and density data from the new standard are summarized for some altitudes in Table I and on certain of the marginal figures; the document itself should be consulted for details. This unit goes beyond the standard atmosphere in that the region above 700 kilometers is discussed and the parameters of composition and wind structure at all altitudes are included.

The atmosphere affects every space vehicle passing through it by the drag force exerted, which is directly proportional to the density of the atmosphere and the square of the space vehicle's velocity. In the low pressure of the upper atmosphere as well as in interplanetary space, the evaporation of metals and bearing lubricants is a consideration in space vehicle design. Physical-chemical reactions on surfaces of instrumentation hardware, enhanced by solar ultraviolet and energetic particle radiation, must also be considered in spacecraft design. An atmospheric effect of importance on space vehicles at lower altitudes is aerodynamic heating and pressure. In the radio tracking of space vehicles and spacecraft, ionization effects on radio transmission must be overcome. The degree of artificial ionization which occurs during reentry of spacecraft into the earth's atmosphere is determined by the density and composition of the atmosphere as well as by spacecraft velocity.

*TABLE I*

| HEIGHT (KM) | TEMP $^0$K | PRESSURE (MB) | DENSITY GM/CM$^3$ |
|---|---|---|---|
| 0.000 | 288.15 | 10.1325 + 2* | 1.2250 + 3* |
| 11.019 | 216.65 | 2.2632 + 2 | 2.6392 + 2 |
| 20.063 | 216.65 | 5.4747 + 1 | 8.8033 + 1 |
| 32.162 | 228.65 | 8.6798 0 | 1.3225 + 1 |
| 47.350 | 270.65 | 1.1090 0 | 1.4275 0 |
| 52.429 | 270.65 | 5.8997 - 1 | 7.5939 - 1 |
| 61.591 | 252.65 | 1.8209 - 1 | 2.5108 - 1 |
| 79.994 | 180.65 | 1.0376 - 2 | 2.0009 - 2 |
| 90.000 | 180.65 | 1.6437 - 3 | 3.1698 - 3 |
| 100.000 | 210.02 | 3.0070 - 4 | 4.9731 - 4 |
| 110.000 | 257.00 | 7.3527 - 5 | 9.8277 - 5 |
| 120.000 | 349.49 | 2.5209 - 5 | 2.4352 - 5 |
| 150.00 | 892.79 | 5.0599 6 | 1.8350 - 6 |
| 160.000 | 1,022.20 | 3.6929 - 6 | 1.1584 - 6 |
| 170.000 | 1,103.40 | 2.7915 - 6 | 8.0330 - 7 |
| 190.000 | 1,205.40 | 1.6845 - 6 | 4.3450 - 7 |
| 230.000 | 1,322.30 | 6.9572 - 7 | 1.5631 - 7 |
| 300.000 | 1,432.10 | 1.8828 - 7 | 3.5831 - 8 |
| 400.000 | 1,487.40 | 4.0278 - 8 | 6.4945 - 9 |
| 500.000 | 1,499.20 | 1.0949 - 8 | 1.5758 - 9 |
| 600.000 | 1.506.10 | 3.4475 - 9 | 4.6362 - 10 |
| 700.000 | 1,507.60 | 1.1908 - 9 | 1.5361 - 10 |

**Power of 10 by which preceding number must be multiplied.*

Pressure, Temperature, and Density

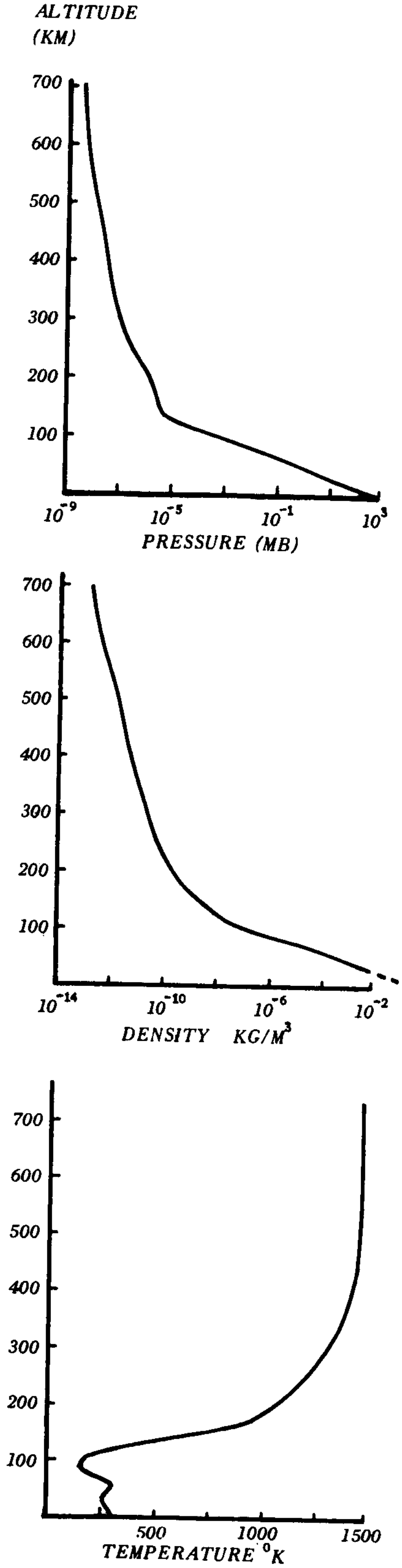
Table I has been extracted from the U. S. Standard Atmosphere, 1962; the entries describe the idealized middle latitude, year-round mean of three atmospheric parameters over the range of solar activity. These means are more valid for the lower levels of the atmosphere where actual observations are more numerous. A distinction is, in fact, made in the referenced document. Tabulated values for the region below 32 kilometers are considered 'standard;' values for the 32–90 kilometer range are 'proposed standard,' while values above 90 kilometers are described as 'speculative.'

The parameters for the region below 90 kilometers have been sufficiently observed that latitudinal and seasonal variations may be distinguished. A detailed presentation of these variations for four latitudes and two seasons will soon be available as supplements to the 1962 standard atmosphere. Variations accompanying change in latitude or season in the region below 90 kilometers may, however, be briefly described as follows. It is estimated that density variations range from a low of about 1 percent of the Table I value at 8 kilometers to a high of about 50 percent near 70 kilometers. Temperature variations range from 4 to 30 percent around the tabulated values. Density variations at 90 km are probably less than at 70 km but increase rapidly above 90 km.

Data are insufficient to define mean values of temperature, pressure, and density parameters for various seasons or latitudes in the 90 to 200 km altitude range; the standard atmosphere values are means of the existing measurements.

One of the recent results of the space program is the finding that there are considerable variations in temperature, pressure, and density above 200 km. These variations have been directly related to solar radiation. A diurnal variation in temperature in the order of 500 degrees K may occur in the region from 200 to 700 km. This temperature fluctuation causes diurnal density variations up to one order of magnitude above the temperature variation at these altitudes. Consistent with the strong correlation between density/temperature fluctuations and solar radiation in the diurnal cycle, fluctuations in density and temperature occur in a seasonal pattern and also in response to solar activity.

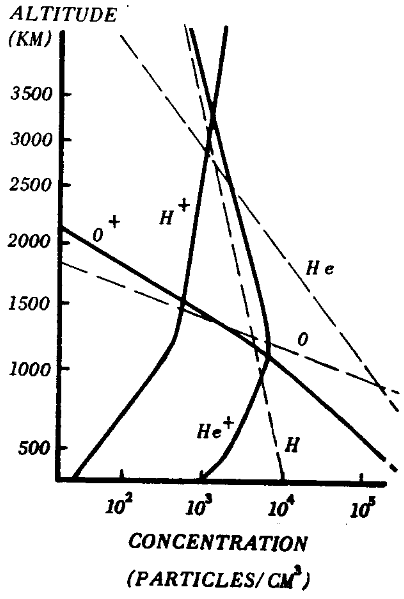
It should be noted that the atmosphere at a given time is nearly isothermal above 300 km. Temperature in these regions is usually deduced from density measurements determined from satellite drag observations.



## Composition

Up to 90 kilometers altitude, the atmosphere is a homogeneous mixture largely of molecular nitrogen (78.08 percent) and oxygen (20.95 percent). Argon and carbon dioxide contribute 0.93 and .03 percent respectively. The trace elements include, in order of decreasing content, the following: neon, helium, krypton, xenon, hydrogen, methane, nitrous oxide, ozone, sulfur dioxide, nitrogen dioxide, ammonia, carbon monoxide, and iodine. Water vapor is present in increasing concentration towards the ground and ozone becomes an important trace element from 20 to 70 kilometers.

Above 90 km the atmospheric constituents tend to concentrate at differing altitudes in atomic form with elements of higher atomic weight predominating at lower altitudes and those of lower atomic weight concentrating at higher altitudes. Thus oxygen is the predominant component from 200 to 1000 kilometers, helium from 1000 to 3000 kilometers, and hydrogen at altitudes above 3000 kilometers. **An increasing proportion of the atoms and molecules above 90 km are ionized with approximately one-half of all constituents being ionized near 1500 km.**

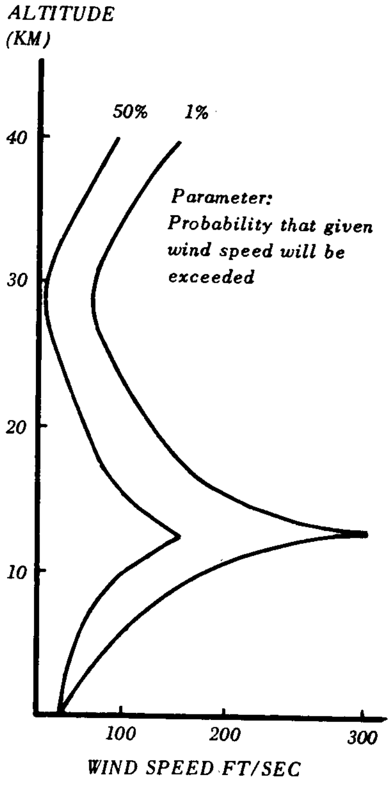



## Winds

The wind structure of the atmosphere, particularly below 90 km, is a function of locale and time; a detailed prediction can generally be extrapolated only for a brief time period following the measurement of existing conditions. Statistical summaries are available for both world wide and local areas, and data are often available for inclusion in summaries for new areas of interest. Such data, however, exist only within the range of balloon measurements (up to 30 km). The material below presents what are the extreme conditions expected over the United States, considering altitudes up to 30 km.

In the winter and over the windiest area of the United States the strongest winds in this altitude range occur between 9 and 12 kilometers altitude. The marginal figure shows the speed profile expected to be exceeded at various probabilities. A speed of 300 feet per second will be exceeded only one percent of the time in the 9–12 kilometer region; the minimum at greater altitudes and the same probability occurs near 24 kilometers and has a value of about 80 feet per second. Available data have also been accumulated and estimates may be made of the probability that the expected wind falls within any range of directions.

Wind data for the region above 30 km are limited. The winds blow generally from east or west directions, and a maximum occurs in all seasons at altitudes from 50 to 60 km. Much higher winds than at lower altitudes have been observed in the 50 to 60 km region and above. These high wind velocities are mainly important, however, in their effect upon atmospheric circulation and do not present a serious problem to space vehicles because the force represented by high winds at these altitudes is relatively small because of low atmospheric density.



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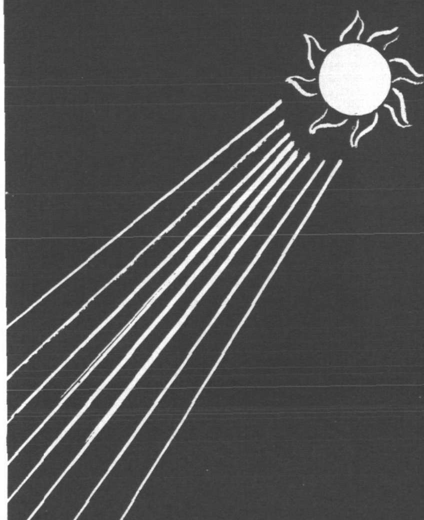
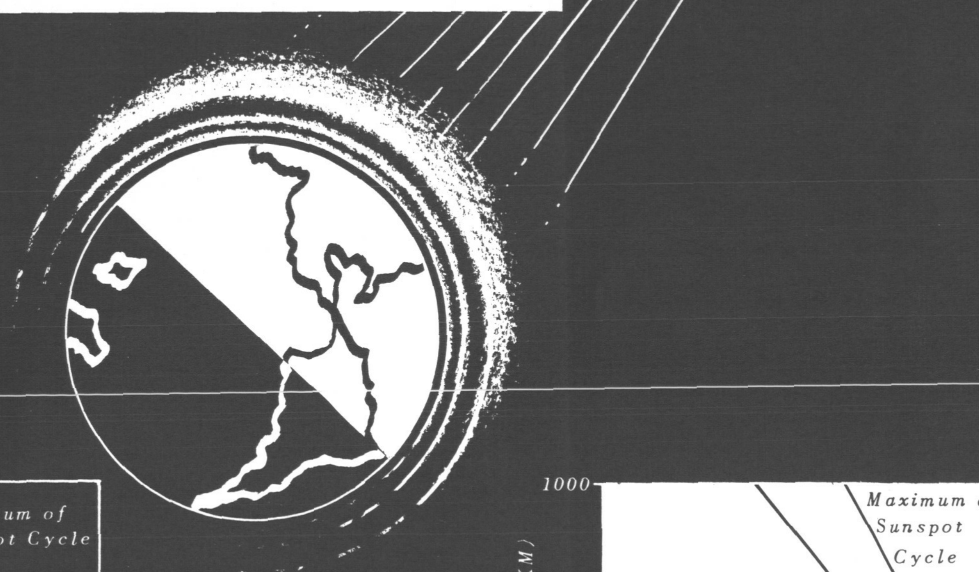
## STRUCTURE OF THE IONOSPHERE

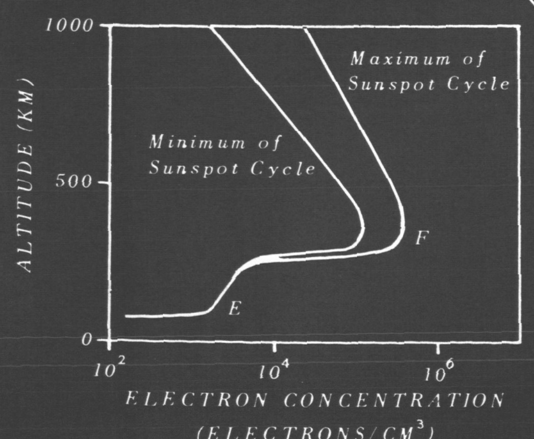
The ionosphere, an atmospheric region characterized by the presence of ionized atmospheric constituents, forms a spherical shell around the earth which begins at approximately 50 kilometers above the surface. If the term is restricted to its older sense, then the upper boundary of the ionosphere is the altitude at which radiosounding techniques become ineffective (about 300 kilometers). This region is, however, under extensive study by satellites and rockets, and research has already shown that the upper boundary is indefinite and that the region extends to the interplanetary plasma.

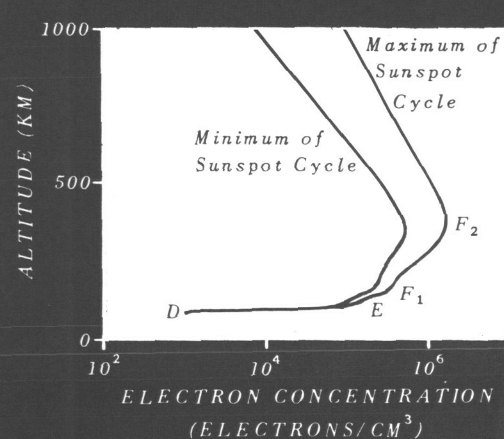
Various ionization reactions, triggered either by solar radiations in the ultraviolet and X-ray regions or by primary and secondary cosmic rays, take place in the ionosphere and are productive of both electrons and the heavier charged particles. The density of both the electrons and the heavier particles at any altitude is a function of the atmospheric composition at that point and of the flux of radiant energy. Thus the ionospheric constituents vary with altitude, time of day, solar cycle, season, latitude, and in the case of the classical $F_2$ region, with longitude.

The most important effects of the ionosphere – the reflection, refraction, and absorption of radio waves–are dependent on the electron density of the ionosphere. A basic finding is that the electron density is not uniform but increases at certain altitudes, giving rise to what are known as the D, E, $F_1$ and $F_2$ regions. These density maxima can be directly related to radio wave reflectivity. For each layer there is a critical frequency; this frequency is the lower limit to the normally incident electromagnetic waves that will not be reflected by the layer.







## D Region

The region of the ionosphere nearest the earth is the D region. Normally it is situated within the altitude range of 50 to 85 kilometers. The D region absorbs radio waves of interest but not so extensively as to reflect or severely refract, as occurs in the E and F regions.

Ionization in the D region is generated principally by Lyman alpha radiation, cosmic rays, and X-rays. There is general agreement that cosmic radiation is the dominant feature in lower D region ionization. In the upper D region the principal ionizing radiation is thought to be, normally, Lyman alpha radiation; the resulting ions being predominantly nitric oxide and molecular oxygen. Shortly after certain solar disturbances, hard X-ray (below 8 angstrom units) fluxes increase to high enough levels to become the principal cause of ionization.

The resulting D region electron concentrations are not easily measured by land-based ionospheric sounding techniques. However, limited data obtained by land-based methods and rocket flights are consistent with an approximate figure for the peak electron concentration of 1000 electrons per cubic centimeter occurring near an altitude of 80 kilometers.

Diurnal and solar cycle effects produce the largest variations in the D region electron densities. The D region is predominantly a daytime phenomenon. During the hours of darkness it all but disappears, except under conditions of increased solar activity. It is thought that the disappearance of the D region at night is caused by recombination of the free electrons with either positive ions or neutral particles. Regardless of the phenomenon, the end result is a decrease in the absorption of radio waves as compared with daylight hours.

Certain types of solar flares are responsible for three types of absorption anomalies and for increases in concentration by as much as two orders of magnitude. The Type I phenomenon occurs at the same time as the solar flare, but only in the sunlit portion of the ionosphere. It is called a sudden ionospheric disturbance (SID) and usually lasts approximately half an hour. The resultant radio blackout is thought to be caused by increased ionization of the lower D region by X-rays emitted from the sun during the flare. The second or Type II phenomenon is associated with aurorae and local magnetic disturbances and takes place mainly at night. Though it is more intense in nature at higher latitudes, it has been observed outside the auroral zone. The enhanced radio wave absorption during these events is thought to be due to an increased ionization from solar particle emission. Polar cap blackouts of the Type III phenomenon occur principally above the auroral zones. These events occur a few hours after a solar flare and can persist for a number of days; their effects are more noticeable during the daylight hours. As might be expected, the occurrence of the above phenomena is closely related to the 11-year sunspot cycle.

*IONOSPHERE*
*D REGION*

*LOCATION*

*50 – 85 KM*

*PRINCIPAL IONIZING RADIATION*

*LYMAN α*

*X–RAYS*

*COSMIC RAYS*

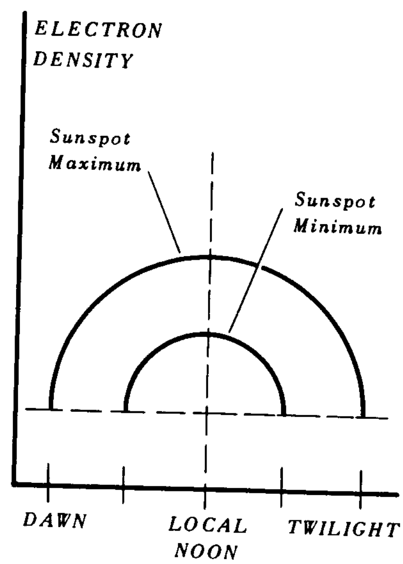
*PRINCIPAL IONS*

$NO^+$ $O_2^+$

*ELECTRON CONCENTRATION AT PEAK*

$\sim 10^3$ *ELECTRONS/* $CM^3$ *AT 80 KM*

*MAJOR VARIATIONS*




*ANOMALIES*

*INCREASED IONIZATION FOLLOWING SOLAR FLARE ACTIVITY*

## E Region

Between 85 and 140 kilometers altitude lies the second or E region. Ionization in the E region is generated principally by solar radiation in the ultraviolet range (170–1027A) and by soft X-rays. Recent data, showing that the ultraviolet intensities are two orders of magnitude greater than formerly believed, have been interpreted to mean that the ultraviolet is the more important radiant. The ionization of molecular oxygen by ultraviolet radiation determines the electron content in region E. Other ions thought to be present in varying quantities are nitric oxide and monatomic oxygen.

Electron densities in the E region obtained from theoretical models as well as by experimental methods are in quite good agreement. Concentrations of approximately 150,000 per cubic centimeter are typical for local noon at sunspot minimum and at 105 kilometers, a typical height for the density maximum.

Diurnal, seasonal, latitudinal, and solar cycle variations of electron densities in the E region occur with a relatively high degree of predictability. The diurnal variation of electron densities is large with the maximum occurring at local noon. The seasonal variation is symmetrical about a maximum occurring during the local summer months. The higher latitudes, though having lower mean densities throughout the year, have a much greater overall change from summer to winter than the lower latitudes. Variations of concentration due to solar activity can amount to an increase of approximately 50 percent from sunspot minimum to sunspot maximum.

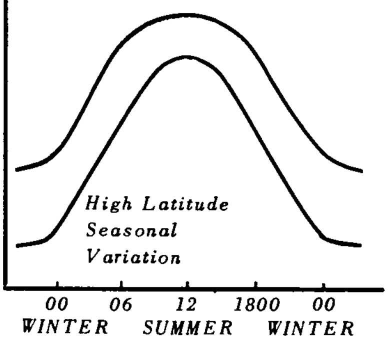
The irregular occurrence of relatively dense concentrations of electrons in the E region at altitudes near 100 kilometers is an anomaly called Sporadic E. Sporadic E densities are roughly twice those in the layer proper. There does not appear to be any correlation between the solar variation and Sporadic E except that the anomalous concentrations occur near the magnetic equator during daylight hours and at higher latitudes at night. In the temperate latitudes Sporadic E occurs much more often in the summer months than in the other seasons. It is thought that Sporadic E is caused by the appearance of localized regions of increased ionization in the main E region and not by increased ionization of the layer proper.

| IONOSPHERE E REGION |
|---|
| LOCATION – 85-140 KM |
| PRINCIPAL IONIZING RADIATION<br>ULTRAVIOLET • SOFT X-RAYS |
| PRINCIPLE IONS<br>$(O_2^+)$ $(NO^+)$ $(O^+)$ |
| ELECTRON CONCENTRATION AT PEAK<br>$1.5 \times 10^5$ ELEC $CM^3$ AT 105 KM |

**MAJOR VARIATIONS**

ELECTRON CONCENTRATION

*Seasonal Variation for Low Latitudes*




**ANOMALIES**

SPORADIC E - LOCALIZED REGIONS OF APPROXIMATELY TWICE THE NEARBY LAYER DENSITY APPEAR; IONIZATION MECHANISM NOT KNOWN

## F Region

The third and highest of the ionospheric regions is the F region. During part of each day, it is actually two regions, denoted as the $F_1$ and $F_2$ regions with the $F_2$ region more distinct than the $F_1$. Throughout the remaining hours, between sunset and sunrise, the $F_1$ region disappears.

Ionization in the F region is caused principally by solar radiation in the ultraviolet range (170–911 angstrom units). The predominant ions formed are molecular oxygen and nitric oxide in the lower $F_1$ region, changing to principally monatomic oxygen in the upper $F_1$ and lower $F_2$ regions. Monatomic oxygen is the predominant ion to about 1000 kilometers for high levels of solar activity. Recent space experiments have

| IONOSPHERE F REGION |
|---|
| LOCATION<br>ABOVE 140 KM WITH TWO LAYERS $F_1$ AND $F_2$ OBSERVED |
| PRINCIPAL IONIZING RADIATION<br>ULTRAVIOLET |

shown that helium ions predominate in a layer of variable thickness above 1000 kilometers. At higher altitudes, hydrogen ions predominate.

Electron concentrations in the F region rise to a maximum between 300 and 375 kilometers and then taper off to the relatively low levels found in space beyond the ionosphere. In the $F_1$ region a typical noon sunspot minimum value for the electron concentration is approximately 250,000 per cubic centimeter at 170 kilometers. Electron concentrations in the $F_2$ region reach a maximum on the order of one million per cubic centimeter at approximately 320 kilometers. The electron concentrations in the F region are highly variable; the variations being a function of diurnal, seasonal, latitudinal, solar cycle, and, for the $F_2$ region, longitudinal effects.

## $F_1$ Region

The $F_1$ region variations are as a rule much more predictable than those of the $F_2$ region. The diurnal variation of the $F_1$ electron densities is generally symmetrical about the local noon maximum during the hours of daylight. At night the densities fall below those measurable by ionosondes (approximately 10,000 per cubic centimeter), and the $F_1$ region becomes indistinguishable from the $F_2$ region. The seasonal and latitudinal variations of the $F_1$ region are also directly related to the zenith angle of the sun, the average local noon maxima for each month being symmetrical about the summer solstice. Concentrations throughout a solar cycle will change by a factor of about 1.75 from sunspot minimum to sunspot maximum.

## $F_2$ Region

The $F_2$ region variations are complex; variations with longitude as well as solar and latitude effects occur.

The diurnal variation has two major characteristics:

(a) The change in electron densities at sunrise and sunset is more abrupt than that in the other ionospheric regions.

(b) In mid latitudes during the winter months daily variations in density tend to be symmetric, with the maximum lagging noon by about two hours; but at other geographical positions and during other seasons the density-time function has two maxima, one before noon and one after. There are other complexities of somewhat lesser importance.

Latitude and seasonal variations are not easily summarized. In general, values of the electron density for latitudes between 50 degrees north and 35 degrees south tend to be higher than average during November, December and January.

There is a gradual increase in electron density from quiet to active sun condition.

All of these variations in density are accompanied by a variation in $F_2$ region height. The height is greater at night in the equatorial region and increases with increasing solar activity.

*PRINCIPAL IONS*

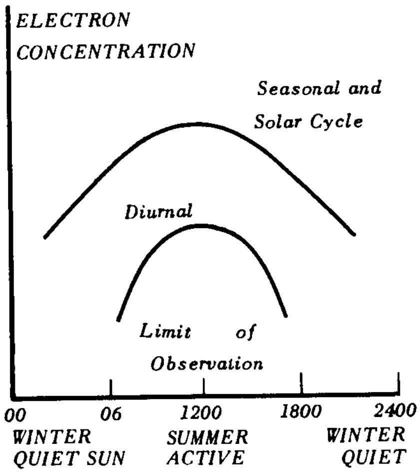
| | |
|---|---|
| LOWER REGION | $O_2^+$ $NO^+$ |
| MIDDLE REGION | $O^+$ |
| UPPER REGION | $He^+$ $H^+$ |

*ELECTRON CONCENTRATION*

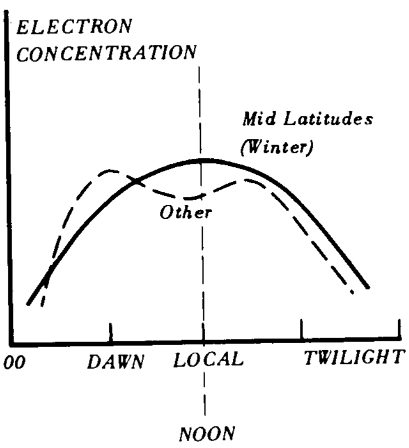
*$2.5 \times 10^5$ ELECTRONS/$CM^3$ AT 170 KM ($F_1$)*

*$10^6$ ELECTRONS/$CM^3$ AT 320 KM ($F_2$)*

*MAJOR VARIATIONS $F_1$ LAYER*




*MAJOR VARIATIONS $F_2$ LAYER*



The major anomaly is the appearance, usually at night, of regions of higher electron densities. This gives rise to a multiplicity of returns to sounding apparatus, hence the term Spread F used in reference to this phenomenon. The frequency of occurrence varies from rare occurrences at 35 degrees geomagnetic to greater frequencies at high latitudes with a quiet sun. In temperate latitudes, Spread F tends to be associated with magnetic disturbances. Recent rocket sounding experiments also indicate a dependence of Spread F on the magnetic field; the multiple returns were believed the result of field guided ducting along magnetic field aligned irregularities. Preliminary data from Ariel and Alouette satellites indicate that irregularities are associated with the Van Allen radiation belts.

### *VARIATIONS NOT PICTURED*

*1) ABRUPT CHANGES AT SUNRISE AND SUNSET*

*2) LATITUDE AND SEASONAL VARIATIONS*

*3) INCREASE WITH ACTIVE SUN*

*4) HEIGHT VARIATIONS*

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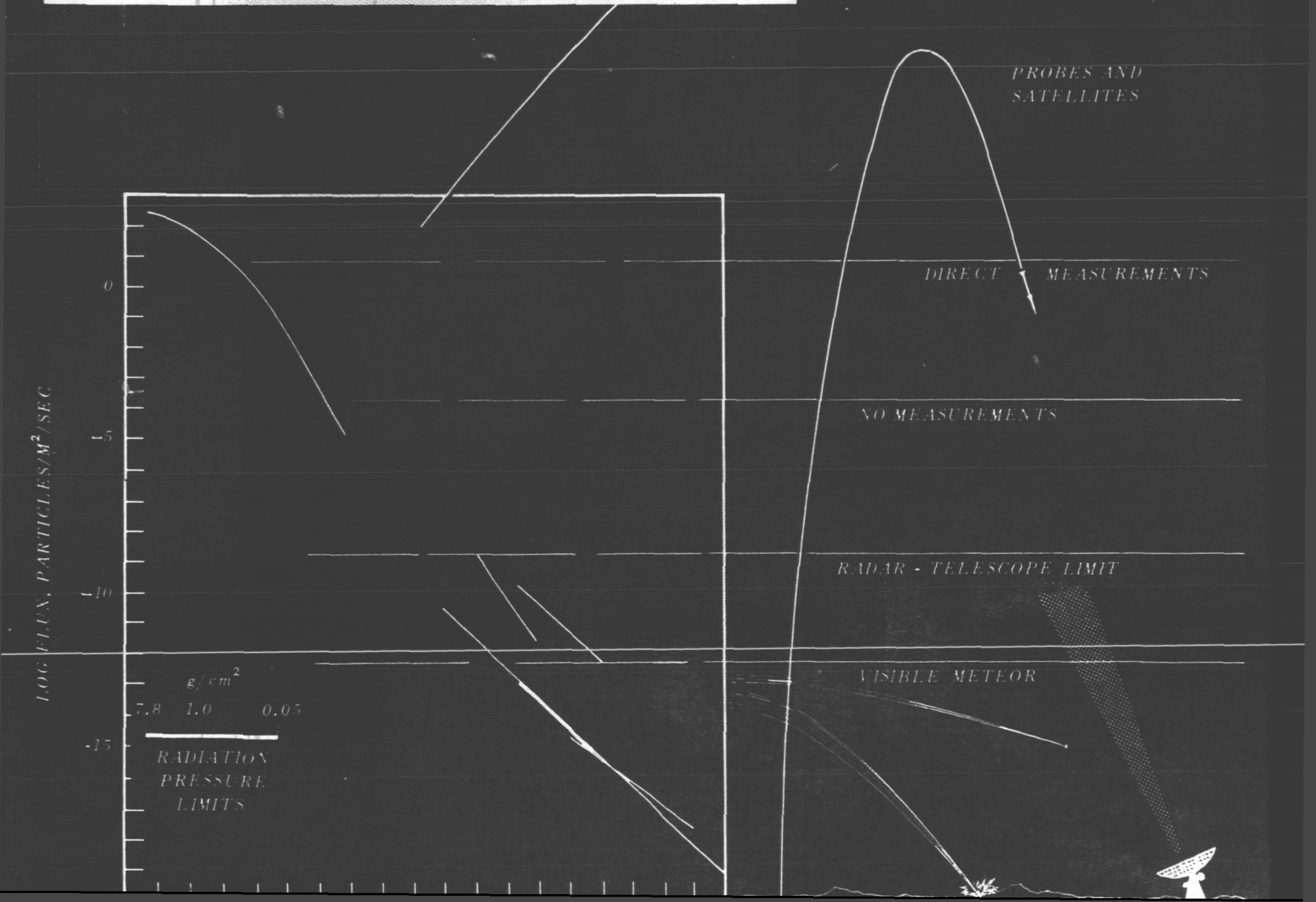
## SOLID PARTICLES

It has long been recognized that meteors are evidence that space must contain solid particles. Study and deduction, particularly that based on visual observations of meteors, has resulted, for the larger particles, in magnitude estimates of the important parameters: the size, density, velocity, flux and spatial distribution. Currently, study of the collisions of the smaller particles with instrumented portions of satellites is adding significantly to existing knowledge.

The solid particles are from one of two sources, comets or asteroids. Ninety percent of the particles found in space are estimated to be of cometary origin.

The principal effect of the solid particles on space vehicles is not structural failure but rather the degradation of the exposed surfaces, particularly those of sensitive instrumentation. Mass-to-flux relationships obtained to date indicate that damage from puncture is secondary to the erosion hazard.



## Physical Characteristics

The solid matter landing on the earth falls into three categories: the iron meteorites (densities 7–8 grams per cubic centimeter), the more numerous stone meteorites (densities 3–4 grams per cubic centimeter), and the 'dust balls' (densities 0.1–2.0 grams per cubic centimeter.) Estimates of mean velocity with respect to the earth range from 15 to 43 kilometers per second, with 30 kilometers per second often used in computations when a single representative value is required. The preponderance of the solid particles is believed to be small (1–100 microns in diameter); particles in this size range are collectively referred to as the interplanetary dust. The bulk of the interplanetary dust is concentrated near the plane of the ecliptic and the separate particles are, as is the earth, in direct, rather than retrograde, orbit around the sun.

There is known to be considerable variation in the physical parameters. There is a lower limit to size imposed by radiation pressure from the sun which sweeps particles smaller than about one micron in diameter from the solar system. There is no definite upper limit to size; bodies many miles in diameter are known to exist. The lower limit to velocity, relative to the earth, is 11 kilometers per second, the velocity acquired by a falling particle initially at rest with respect to the earth.[1] The upper limit, 72 kilometers per second, is obtained by adding the earth's orbital velocity to the velocity a particle would need to escape the solar system from an orbit about the sun at one astronomical unit.

Recent satellite experiments have been designed to measure the solid particle flux (the number of encounters per unit area per unit time) for particles too small to produce a meteor detectable by visual, optical, or radar techniques. As shown in the introductory figure, the measured flux of the smaller particles prove to be greater than would be expected by extrapolation of the older data. Of particular interest, therefore, will be those future studies of the flux in the yet unknown region between the two sets of data. Finally, the introductory figure shows what is called the sporadic, or average, particle flux. Meteor showers are a well known and often occurring phenomenon and flux rates at a shower peak can rise to values which are four or five times the sporadic rate.

The concentration of the greater bulk of the solid material, i.e., the interplanetary dust, in the plane of the ecliptic has been noted. Deductions based on observations of the zodiacal light indicate that the dust concentration is highest near the sun and that the concentration diminishes roughly in inverse proportion to the three halves power of the distance from the sun. There is some evidence that the concentration may be slightly elevated in the immediate vicinity of the earth.

**SOLID PARTICLES**

*TYPES AND DENSITIES*

| | |
|---|---|
| *IRON* | *7–8 $GM/CM^3$* |
| *STONE* | *3–4 $GM/CM^3$* |
| *DUST BALLS* | *.1–2 $GM/CM^3$* |

*MEAN VELOCITY*

*30 KM/SEC*

*SIZE RANGE*

*1 MICRON TO MANY MILES*

*VELOCITY RANGE*

*11 KM/SEC – 72 KM/SEC*

*VARIATIONS*

1) *FLUX RATES 4 or 5 TIMES HIGHER DURING METEOR SHOWERS*

2) *CONCENTRATION IS HIGHER BOTH IN THE PLANE OF THE ECLIPTIC AND IN THE REGIONS NEAR THE SUN*

---

[1] *If any particles are trapped in geocentric orbits near the earth, the relative velocities may be as low as 8 km/sec. EGO will attempt to detect particles in geocentric orbits.*

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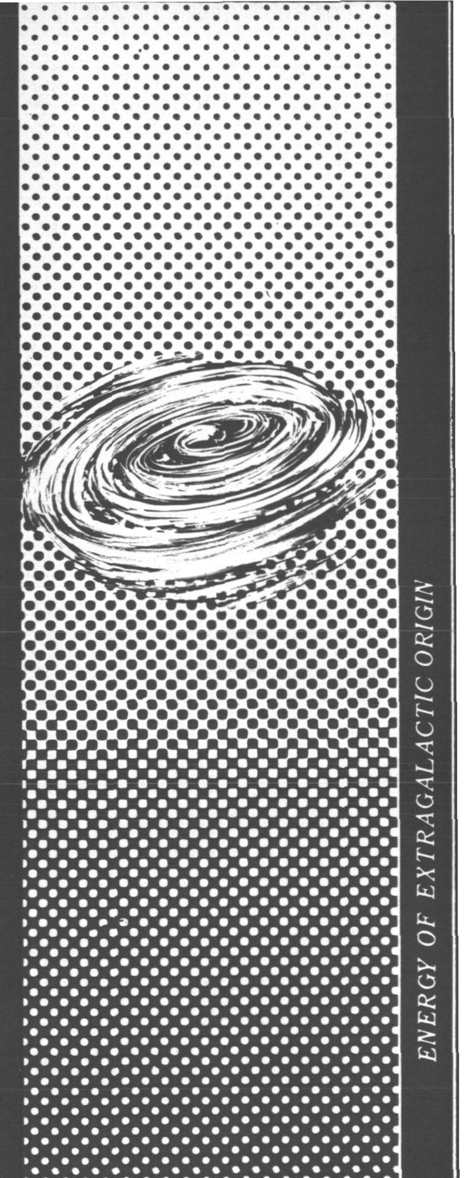
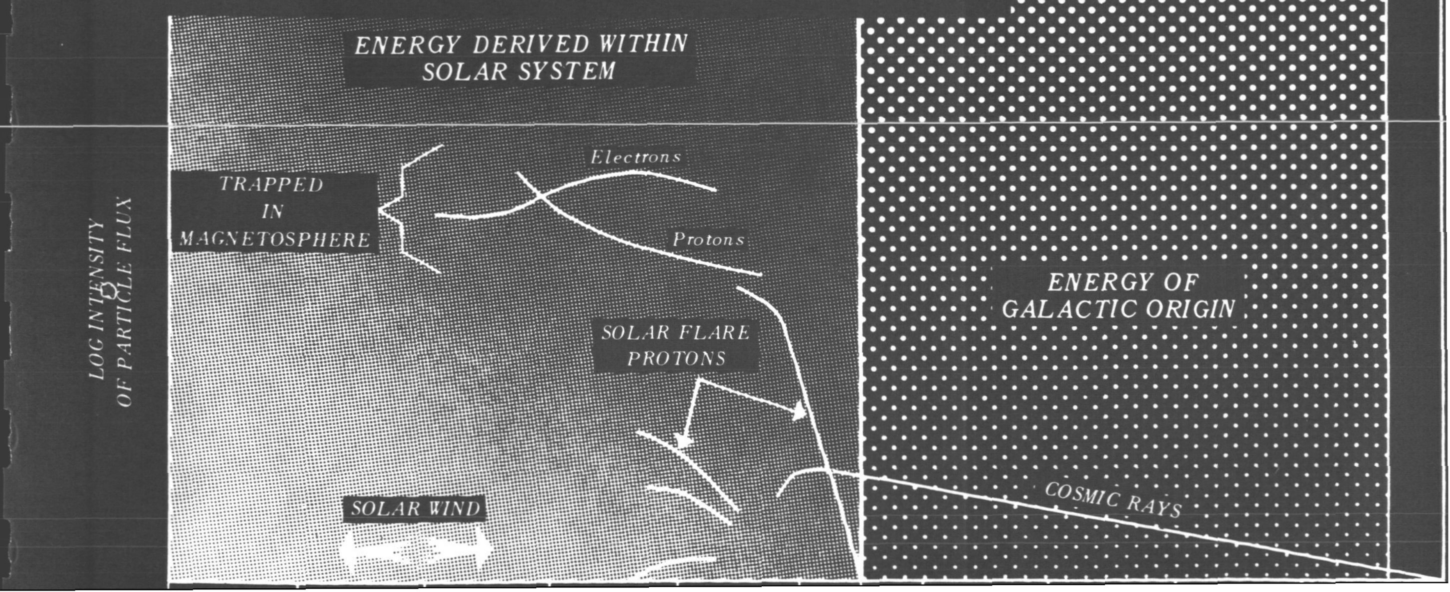
## ENERGETIC PARTICLES

The existence of charged atomic and subatomic material in the space environment has long been deduced from the study of cosmic ray events at the earth's surface. Further understanding resulted from data taken in those atmospheric regions accessible by balloons. The advent of rockets, satellites, and deep space probes has added significantly to knowledge, but understanding is not yet complete. It is known that these particles are both plentiful and of various types and that they have energies extending over a broad range. Not completely known are the complex processes which propagate and distribute the penetrating particles nor is their origin definitely established. The majority, if not all, of the energetic particles in space are apparently by-products of the nuclear reactions occurring in the stars, but other sources have been proposed. The energetic particle flux in the near earth region, in fact, can be looked upon as a summation of charged, energetic material contributed from the entire universe and basically isotropic in nature, upon which special concentrations and orientations are imposed--since these particles are charged--by the magnetic fields of the sun and the earth.

The most useful classification of these particles, for the purpose of exposition, is not by source, however, but in terms of their energy. When displayed upon an energy scale, as in the introductory figure, four categories, which include the important phenomena, can be discerned: galactic cosmic radiation, solar cosmic radiation, the solar wind, and radiation trapped in the earth's magnetosphere. These categories are used in the following discussion.

The effects of the various energetic particles on space missions can be serious, since both men and equipment are adversely affected by high radiation dose rates. Intensities of the radiation trapped in the earth's field and intensity increases resulting from solar storms are sufficiently high to yield a dangerous dose even for short missions and shielding must be provided. The potential effect of these particles on exposed surfaces must also be considered; it is known, for example, that solar cells are rendered inoperative by radiation unless protected. Also, the wide range of intensities compounds the difficulties of the designer of probes which are directly intended for the measurement of, or indirectly affected by, the presence of charged particles.



Particles with energies in excess of 10 mev are usually classed as galactic cosmic radiation. Energies of some of these particles are so high that their radius of curvature in the interplanetary magnetic field is of the same order of magnitude as the size of our galaxy, thus 'local' origin is unlikely. Most of those observed, however, presumably originate in our galaxy. The favored theory is that the cosmic radiation is a byproduct of the reactions that lead to a supernova. Theories have also been proposed which postulate both a beginning, with lower energies, in surface eruptions from the stars and then an acceleration process, depending on the magnetic fields in space, to bring the particles to their observed high energies.

Hydrogen nuclei constitute the greater percentage of the galactic cosmic radiation. In order of decreasing abundance occur the nuclei of helium; of the carbon, oxygen, nitrogen group; and of neon, etc., to atomic numbers as high as 26 (iron) and the nuclei of the boron, lithium, beryllium group. Electrons also occur as a minor constituent. Because of the widely distributed sources and the long, curved pathways of these particles, the radiation as perceived at some point in space is essentially isotropic, i.e., equal intensities are measured for any direction of observation. The galactic particle flux in the near earth region lies between 1 and 3 particles per square centimeter per second with the particle flux versus energy spectrum beginning near $10^7$ ev, rising rather abruptly to a peak flux at 1 bev, and falling off with higher energy in approximate inverse proportion to the energy raised to the 2.5 power.

Although the net result of the transit of galactic cosmic rays through the magnetic fields of space is to produce evenly distributed radiation, departures from the isotropic condition are to be expected in regions dominated by strong 'local' magnetic fields. These fields affect the number of particles reaching a point as well as the isotropic distribution. The magnetic fields associated with the sun thus tend to shield the earth from cosmic radiation, tending to bend away particles which would otherwise proceed to the earth. There is a result about a 3 to 1 change in cosmic ray intensity near the earth over the solar cycle, with the intensities lower at the time of solar maximum. Flare activity on the sun can in some cases increase the magnetic field over a large region in space; when the earth is included within such a region, cosmic ray intensities fall (the phenomenon is known as the Forbush decrease) by a variable factor which can be as high as 15 percent of the norm. Variations in cosmic ray intensities as measured at the earth's surface itself include those in the near earth region with added complications due to the presence of the earth's atmosphere. At altitudes between 15 and 35 kilometers, the incoming primary cosmic particles hit and shatter atoms in the air introducing a new phenomenon: a complex distribution of less energetic secondary particles which shower down to the earth's surface. The flux of these secondary particles varies with altitude, latitude, longitude, and solar activity.

## *GALACTIC COSMIC RADIATION*

### *ENERGIES*

*$10^7$ – $10^{19}$ ev*

### *ORIGIN*

*UNIVERSE*

### *COMPOSITION*

*NUCLEI OF:*

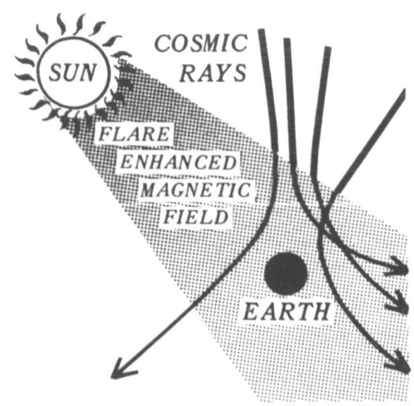
| | |
|---|---|
| H | 85% |
| He | 12% |
| C, N, O | 1% |
| Ne and greater | ~ .25% |
| B, Li, Be | ~ .25% |
| ELECTRONS | ~ 1–3% |

### *FLUX*

*1–3 PARTICLES/$CM^2$/SEC*

### *VARIATIONS*

1) *3 TO 1 CHANGE WITH SOLAR CYCLE*
2) *AS HIGH AT 10% WITH FLARE ACTIVITY*




3) *WITH PENETRATION INTO THE ATMOSPHERE*
4) *WITH LATITUDE AND LONGITUDE ON EARTH'S SURFACE*

## Solar Wind and Solar Flares

Recent space experiments have shown that the solar atmosphere extends in tenuous form as an ionized gas to distances beyond the earth's orbit and that two dynamic phenomena exhibited by this atmosphere, the solar wind and solar flares, are of importance as sources of particles which reach the near earth regions. The term solar wind refers to the steady escape of ionized particles from the sun, moving in radial paths as a result of processes not completely understood but which have been conceived as a continuous expansion of the solar atmosphere. Flare phenomena are abrupt, explosive ruptures of tremendous energy in the visible solar surface which result in increased electromagnetic radiation and in increased particulate radiation, largely protons, from the sun. Solar wind particles are of low energy, but flare-ejected particles can reach the high energies typical of the galactic cosmic rays.

*SOLAR PARTICLES*

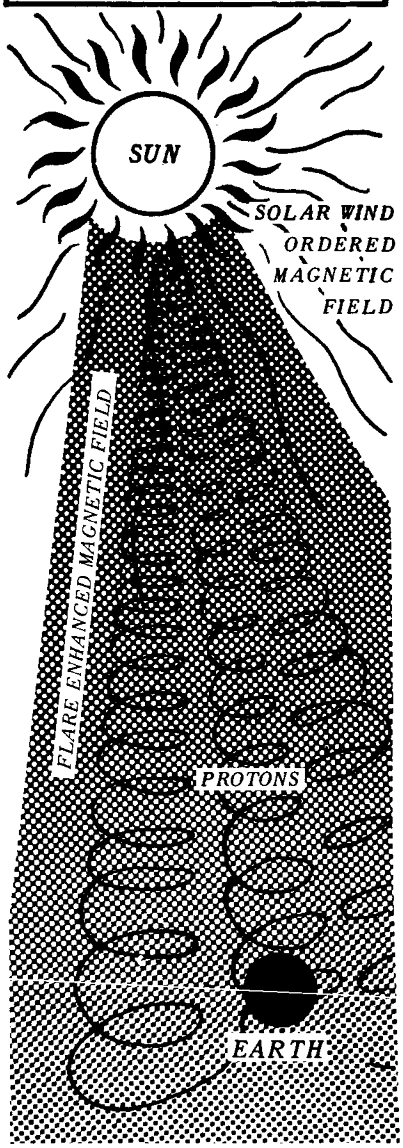
*SOLAR WIND*

*CONCENTRATION:*
*10 PROTONS/CM$^3$*
*VELOCITY:*
*500 KM/SEC*
*ENERGY:*
*1.5 KEV*

*SOLAR FLARES*

*VELOCITY:*
*TO NEAR LIGHT SPEED*
*ENERGY:*
*AS HIGH AS 10 BEV*

**The consensus is that the solar wind is a plasma, i.e., a neutral assemblage of protons and electrons. Presumably the wind is continual. A wide variation exists in reported values for the particle concentrations in the solar wind ($10^{-1}$ to $10^3$ per cubic centimeter),** and in the velocities ($10^1$ to $3 \times 10^3$ kilometers per second). Explorer 10 measurements showed plasma densities from 6–20 protons per cubic centimeter and an energy spectrum peaked at 500 ev. Mariner 2 measurements gave an energy range from 750 to 2500 ev. The figure of 10 protons per cubic centimeter with a velocity of 500 kilometers per second (1.5 kev) was recommended in a recent NASA summation as a quiet day value.

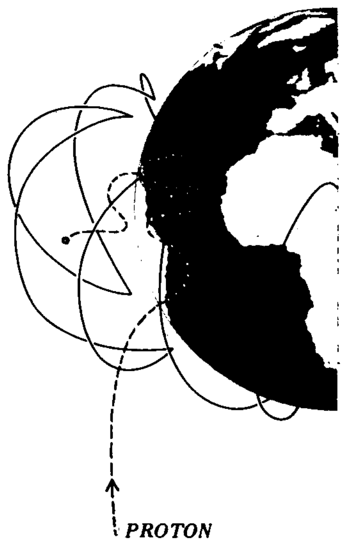



Generally speaking, the earliest solar flare proton arrivals at a point in the near earth region show directionality since they have been guided along a favorably configured magnetic field. Later arriving protons tend to come from all directions, having traveled over longer, more devious pathways or having been trapped within a magnetic field configuration which favors an isotropic arrival pattern. As these last statements imply, the magnetic field between earth and sun is not a static field. Moving plasmas carry along the magnetic fields with which they were originally associated; thus the solar wind carries along a portion of the sun's magnetism and imposes a rough radial order on the interplanetary magnetic field between sun and earth. A large portion of the complexities in solar flare proton phenomena is believed due to the fact that flares, in their early stages, increase the solar plasma emission sharply along the line of a solar radius drawn through the flare. The field between the earth and sun may, as a result of such plasma bursts, be made even more favorable for proton propagation to the near earth region; also, as pictured in the marginal drawing, the resulting field can enhance an isotropic proton arrival pattern.

Flare phenomena are highly variable both because of the varying magnetic field conditions between sun and earth and because of variations in the processes within the sun that generate the particles. It has been said that the most typical feature of flare phenomena is their variability. Proton velocities can rise to near light speed during a relativistic flare. Energies of 1 mev to 1 bev are typical of the non-relativistic flare particles and some major flares eject particles with energies as high as 10 bev, i.e., in the galactic cosmic ray range.

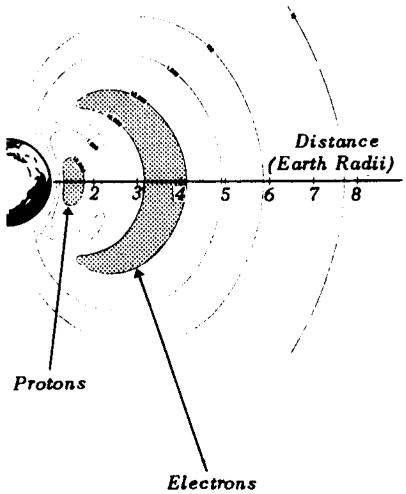
## Trapped Radiation

*TRAPPED PARTICLE MOTION*




One of the earlier and more spectacular findings of the space program was the discovery that the earth is surrounded by toroidal shaped belts of energetic protons and electrons. These belts were named the Van Allen Radiation Belts after their discoverer, James Van Allen. Controversy still exists as to the ultimate source of the Van Allen particles; theories postulating the sun and/or the earth's atmosphere have been proposed as sources. The trapping mechanism is, on the other hand, well understood. Charged particles of proper energy and direction entering the earth's magnetic field are forced into pathways that spiral around magnetic lines of force. Not all particles spiral down to the surface or into the atmosphere along these paths; for many, as the earth's surface is approached, the spiral flattens until the spiraling motion is actually reversed and the particle spirals back to the other side of the earth. The spiral again flattens, the motion is repeated, and the trapped particles spiral back and forth from one hemisphere to the other. It should be added that each loop of the spiral is 'tighter' on the side nearest the earth and the cumulative effect of this is a drift in longitude superimposed on the hemisphere-to-hemisphere motion.

*COUNTING RATE CONTOURS*




The marginal figure shows counting rate contours for unshielded geiger tubes in Pioneer 3 and Explorer 4 flown through the radiation belts. The major features of the belts are easily identified. Their contours follow the lines of the earth's magnetic field with an open region over both poles. There are two regions of concentration where the counting rate peaks--the one at 1½ earth radii is caused by fast-moving protons; the maximum at 3–4 earth radii is due to energetic electrons. However, protons and electrons of lower energy are known to penetrate the whole trapping region, and the Van Allen region can be pictured as a region more or less homogeneous in character and populated by low energy electrons and protons ($10^4$ kev) having roughly equal flux values of $10^7$ particles per square centimeter per second and energies of tens of thousands of electron volts. Superimposed on this steady background are two regions where flux values are much lower and energies considerably higher. The innermost of these regions is the proton belt, which has a flux value of $\sim 10^2$ particles per square centimeter per second in the 10–100 mev range, with the flux value dropping sharply at higher energies. The outermost of these regions consists of high energy electrons which have a peak flux between $10^3$ and $10^6$ particles per square centimeter per second for energies above 1 or 2 mev. Finally, a glance at the cover figure shows that while the energy of Van Allen particles is between $10^3$ and $10^9$ electron volts the number of particles is such that peak intensities within the belt can be significantly higher than for solar flare particles or cosmic rays.

Of the two belts, the inner or proton belt is the more stable. Flux in the outer zone can vary in less than a day by a factor of ten or more, while flux in the lower zone has been observed to require a year for a change of a factor of three.

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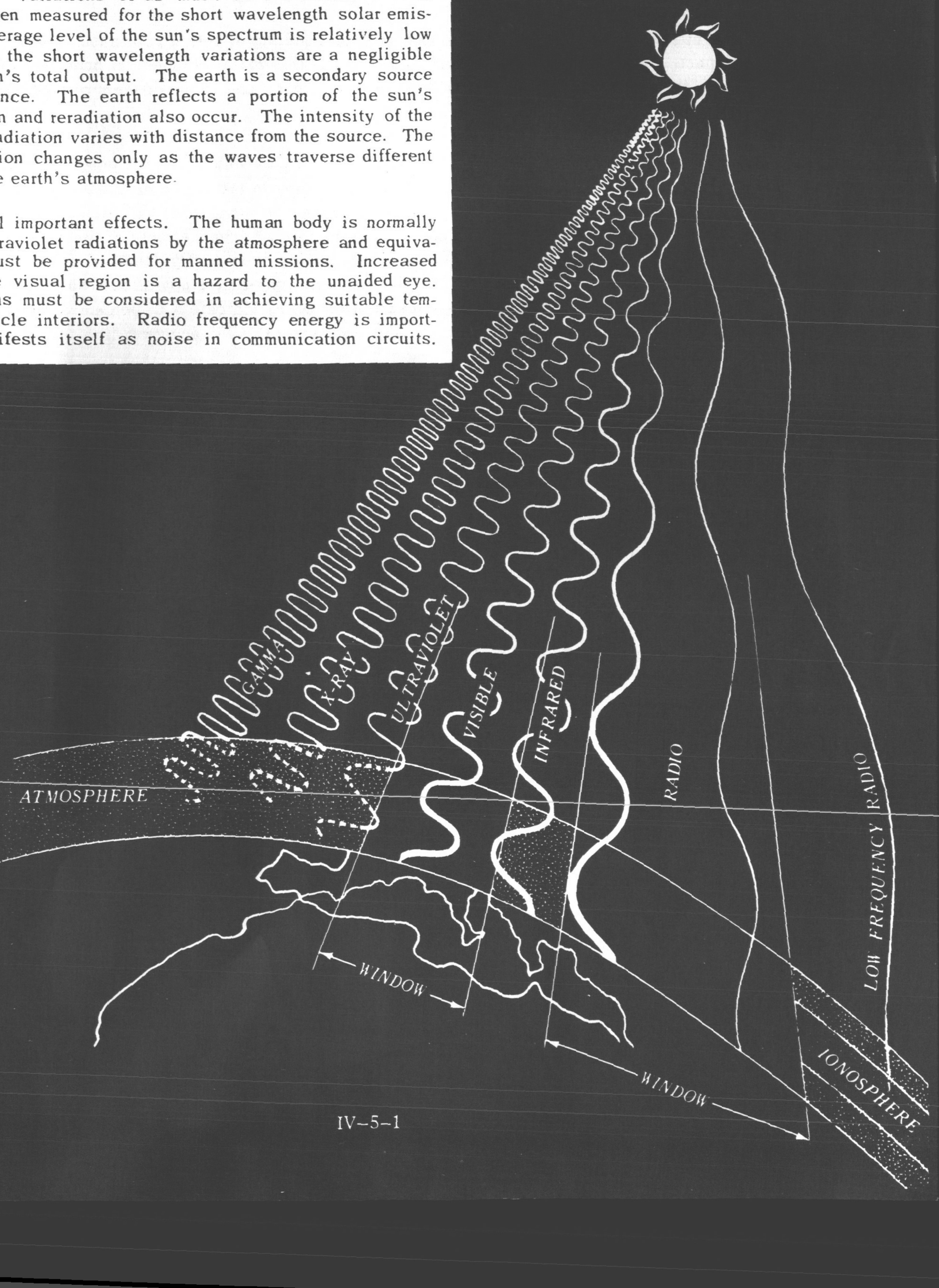
## ELECTROMAGNETIC RADIATION

Electromagnetic waves with wavelengths extending across the measurable spectrum are an important factor in the interplanetary environment. Radiation occurs in the X-Ray, ultraviolet, visible and infrared regions and at radio frequencies.

The source of major importance in the near earth region is, of course, the sun. The total radiated energy (producing a flux of 0.140 watts per square centimeter at the earth's mean distance) is remarkably constant and largely concentrated in the visible region of the spectrum. Variations of as much as a thousand fold in intensity have been measured for the short wavelength solar emissions, but the average level of the sun's spectrum is relatively low in this region and the short wavelength variations are a negligible fraction of the sun's total output. The earth is a secondary source of lesser importance. The earth reflects a portion of the sun's energy; absorption and reradiation also occur. The intensity of the electromagnetic radiation varies with distance from the source. The spectral distribution changes only as the waves traverse different media, notably the earth's atmosphere.

There are several important effects. The human body is normally shielded from ultraviolet radiations by the atmosphere and equivalent shielding must be provided for manned missions. Increased luminance in the visual region is a hazard to the unaided eye. Thermal radiations must be considered in achieving suitable temperatures in vehicle interiors. Radio frequency energy is important when it manifests itself as noise in communication circuits.



## Electromagnetic Radiation from the Sun

Solar radiation in the ultraviolet and X-ray regions constitutes only .2 percent of the sun's total emission. Flux levels are low and, with one or two exceptions, lie between .001 - .0001 microwatts per square centimeter in a one-angstrom band. In contrast to other regions of the solar spectrum, this region has strong emissions at particular wavelengths; the strongest (Lyman alpha) having a flux value of about .1 microwatts per square centimeter in a one-angstrom band.

The ultraviolet and X-ray emission from the sun consists of both a continuous spectrum and a line spectrum typical of highly ionized atoms. Since this radiation does not penetrate the atmosphere, the X-ray and ultraviolet region is not well known and is the concern of continuing rocket and satellite experiments.

Some inconsistencies still exist in measurements of flux values and the complete story on variation with time is not yet available. Ten-fold variation in the region below 140 angstroms has been observed to be correlated with the solar cycle, and significant variations accompany solar flare activity. Flare variations tend to take the form of enhancements of the very short wavelengths, wavelengths as short as 0.2 angstrom having been briefly observed. Current Orbiting Solar Observatory experiments are concerned with long-time study of both spectral lines and the continuous spectrum; preliminary results from OSO I indicate a 15 percent enhancement for the 304 angstrom line and a 28 percent enhancement for the 284 angstrom line during a class 2 plus solar flare.

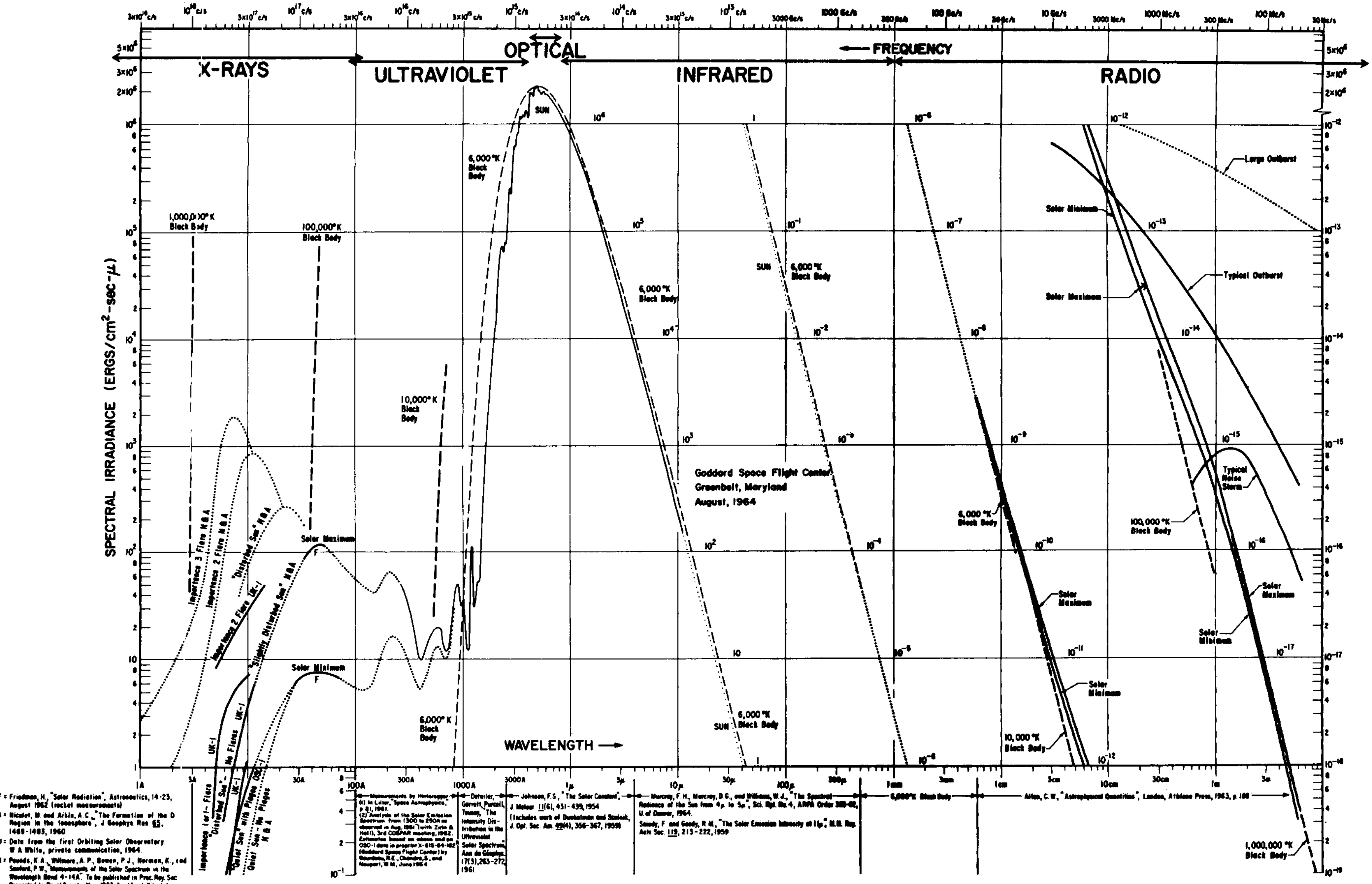
The peak in the solar emission spectrum occurs in the visible region. Radiation in the visible and infrared regions is a continuum explainable as 6000°K black body thermal radiation from the sun's photosphere. Numerous absorption lines and bands appear as a result of selective absorption by various constituents of the solar and terrestrial atmospheres. The terrestrial atmospheric constituents which give rise to the so-called telluric absorption lines and bands in the spectrum are well known and various techniques exist for predicting the solar spectrum at intermediate altitudes.

Since the visible and infrared waves carry a large percentage (99%) of the emitted solar energy, total flux values for these spectral regions are well approximated by the tabulated solar constant, which gives the total, above atmosphere flux at one astronomical unit. The visible and infrared emission of the sun is remarkably constant. The solar constant varies, predictably, with the earth-sun distance, but short term variations are smaller than 1 percent.

Solar radio waves are observed from the upper limit of the infrared waves to waves of 20 to 30 meters length. Longer waves do not penetrate to the earth's surface through the ionosphere. The steady state flux at the mean earth-sun distance is low and falls off with increasing wavelength.

Radio waves are emitted from solar regions lying above the photosphere with the shorter waves radiating from the level of the chromosphere and the longer waves from the corona, or outer solar atmosphere. The temperature of the equivalent black body is thus considerably higher than for the visible wave emission from the cooler photosphere.

The radio wave flux values are low except when certain solar flares occur. Levels can then increase by as much as a millionfold at the long wavelengths. Not all wavelengths are equally affected and the duration of the effect is variable, sometimes lasting more than a day. These transient effects are strong enough to produce severe interfering noise in communication circuits.




# THE SOLAR SPECTRUM

Electromagnetic Radiation from the Earth

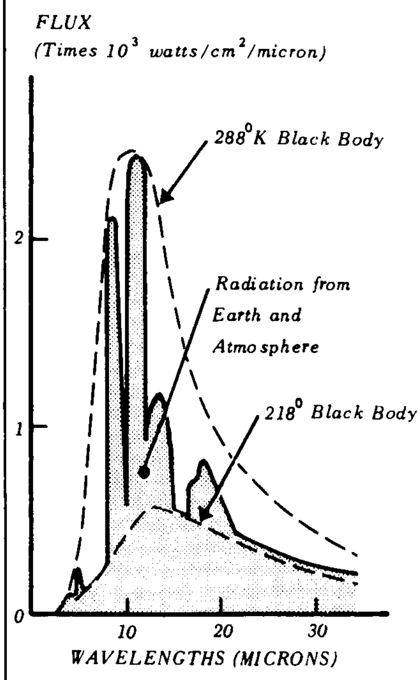
Radiant energy from the sun is in part reflected from the earth; also a fraction of the solar energy absorbed is reradiated in a continuous spectrum in the infrared. There are atmospheric absorption bands and an atmospheric window in this spectral region so that reradiation from the earth is in part from the earth's surface through the window (8 to 12 microns) and in part from the atmosphere. Reflection of solar radiation produces the greater fraction of the reversed flux in the .2 to 6 micron region.

The fraction of the solar energy reflected into space is known as the albedo, and direct measurements have been made of this quantity by the Tiros satellites. Reported reflectance values range from a low of 7 percent over the tropical Atlantic to a high of 55 percent over a dense overcast above the East Central United States.

The black body radiation from the earth in the 8 to 30 micron range has a peak near 10 microns with 288 degrees Kelvin black body radiation used as an approximation to the radiation from the surface and a 218 degrees Kelvin model for those spectral regions where the atmosphere is opaque. Tiros data show that in most cases the equivalent black body temperature for the window region corresponds closely to the temperature of the earth's surface.

The solar reflected energy input to an orbiting vehicle can be expected to be quite variable and to depend on the nature of the surface and the cloud cover underneath. Variations in albedo and equivalent black body temperatures have already been noted. Precise determinations of the total input energy, both reflected and radiated, require a knowledge of the vehicle's altitude and its orientation with respect to that portion of the earth's surface which is being illuminated by the sun.

**RADIATION FROM EARTH**




*VARIATIONS*

1) WITH ALBEDO (RANGE 7–55%)
2) WITH VEHICLE POSITION AND ORIENTATION

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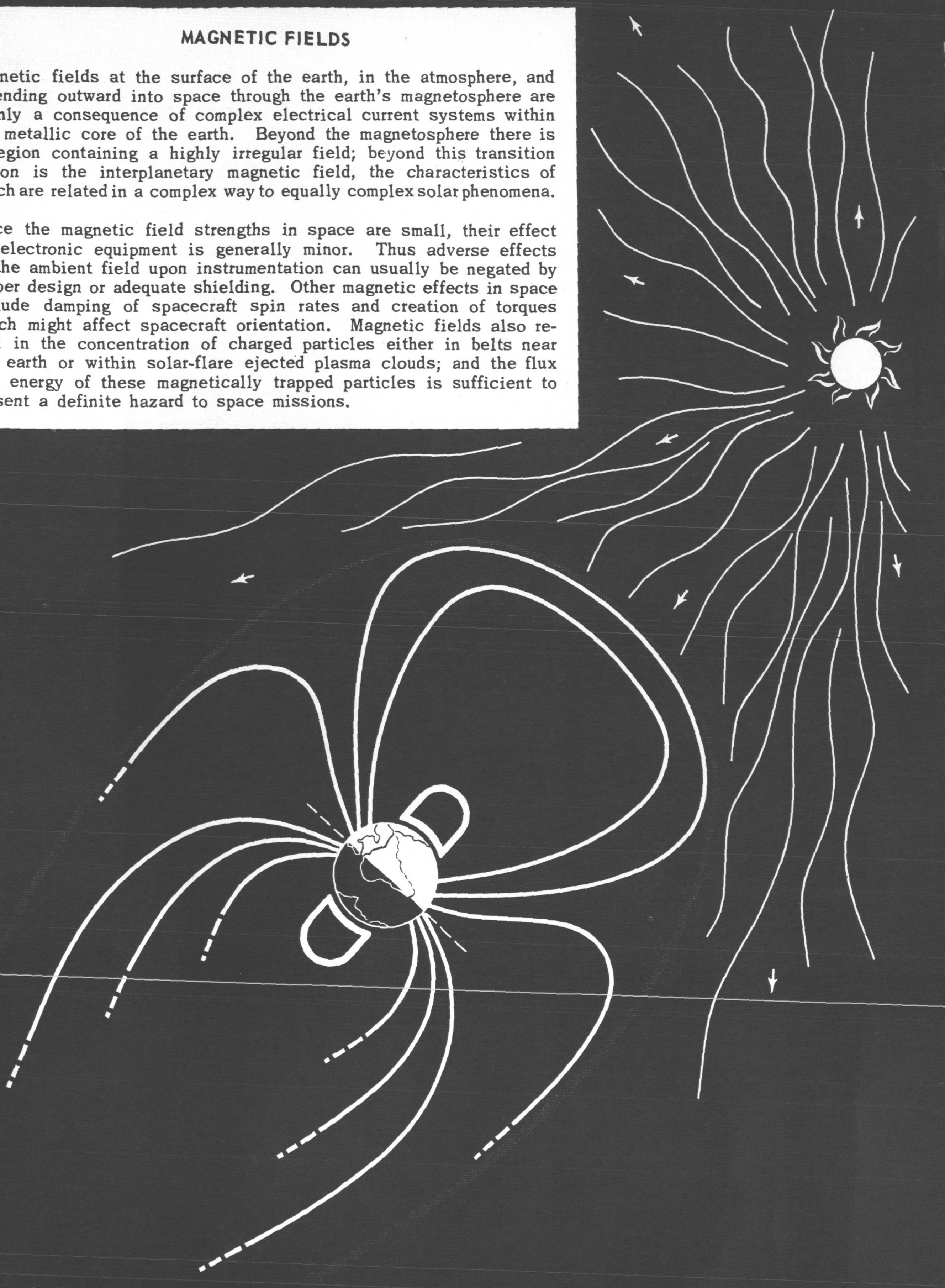
## MAGNETIC FIELDS

Magnetic fields at the surface of the earth, in the atmosphere, and extending outward into space through the earth's magnetosphere are mainly a consequence of complex electrical current systems within the metallic core of the earth. Beyond the magnetosphere there is a region containing a highly irregular field; beyond this transition region is the interplanetary magnetic field, the characteristics of which are related in a complex way to equally complex solar phenomena.

Since the magnetic field strengths in space are small, their effect on electronic equipment is generally minor. Thus adverse effects of the ambient field upon instrumentation can usually be negated by proper design or adequate shielding. Other magnetic effects in space include damping of spacecraft spin rates and creation of torques which might affect spacecraft orientation. Magnetic fields also result in the concentration of charged particles either in belts near the earth or within solar-flare ejected plasma clouds; and the flux and energy of these magnetically trapped particles is sufficient to present a definite hazard to space missions.



## Earth's Magnetic Field

The earth's magnetic field extends outward from the core of the earth into space. Above the ionosphere, it is called the magnetosphere. Satellite measurements indicate that the magnetosphere is not a perfect sphere but extends about 10 earth radii in the direction of the sun (Explorers 12 and 14) and least 20 earth radii directly away from the sun. (Explorer 10).

Although the magnetic field at the surface of the earth is highly irregular, it can, in general, be conceived as resulting from a magnetic dipole located near the center of the earth. The total strength of the surface field varies between approximate maxima and minima of 0.7 and 0.25 gauss. Irregularities arise from terrestrial and extraterrestrial influences.

Terrestrial influences include crustal differences in ferromagnetic content which cause local anomalies in the magnetic field at the earth's surface. Major irregularities in the surface field are believed related to the distribution and orientation of internal current and eddy systems within the molten core of the earth. These currents are continually but slowly changing in form and intensity, giving rise to secular or long-term changes in the surface field. The secular change in most areas amounts to less than two tenths of one percent per year.

Extraterrestrial phenomena are also responsible for changes in the magnetic field on the earth's surface. These variations are of short duration and have been observed to be related to solar disturbances as well as to diurnal, seasonal, and solar cycles. Duration of these deviations ranges from a fraction of a second to several days with changes in intensity ranging from .01 to several hundred gamma (1 gamma equals .00001 gauss) except in the auroral zones where considerably larger changes are not uncommon.

The two most important factors of change are the diurnal cycle, resulting in intensity changes of 50 gamma in middle latitudes and up to 200 gamma at the magnetic equator; and magnetic storms, arising from solar disturbances, which result in variations of several hundred gamma except in the auroral regions where changes up to 2,000 gamma can occur.

Values of magnetic field strengths at the surface of the earth may be used to obtain good approximations of field strengths up to an altitude of 5 earth radii since field strength in this inner region diminishes with rising altitude roughly in inverse proportion to the cube of the distance to the center of the earth. Thus, levels on the order of 0.10 gauss will be found at a mean altitude of 4000 kilometers. Above 5 earth radii the magnetosphere has a greater field strength than would be indicated by the relationship with surface intensities prevailing for altitudes below 5 earth radii.

### EARTH'S MAGNETIC FIELD

**EXTENT**

FROM 10 EARTH RADII IN THE DIRECTION OF THE SUN TO OVER 20 RADII IN OPPOSITE DIRECTION

**STRENGTH**

BETWEEN .25 AND 0.7 GAUSS AT SURFACE

**ANOMALIES AND VARIATIONS**

1. CAUSED BY CRUSTAL DEPOSITS
2. BY CHANGES IN THE EARTH'S INTERNAL CURRENT SYSTEM
3. SOLAR ACTIVITY AND CYCLES
4. DIURNAL CHANGES OF AS MUCH AS 200 GAMMA
5. CHANGES OF 2000 GAMMA DURING MAGNETIC STORMS
6. EXTRAPOLATIONS OF SURFACE FIELD ARE GOOD TO APPROXIMATELY 5 EARTH RADII

## The Interplanetary Magnetic Field

At about 10 to 15 earth radii in the direction of the sun and to greater distances in the direction away from the sun, between the magnetosphere and the interplanetary magnetic field, there appears to be a turbulent transition field. Here, extreme variations are present in both the strength and direction of the magnetic field vector as a result of interaction between the magnetosphere and the magnetic field carried along by charged particles emitted from the sun. Beyond the transition region in all directions the magnetic fields associated with the solar particles become predominant. In these fields there is a continual component from the solar particle emission (the solar wind) which extends the solar magnetic field into interplanetary regions. There is also an important but irregular component related to the increased particle emission that accompanies solar flare activity. In the absence of flare activity, the interplanetary magnetic field immediately beyond the transition field has intensities on the order of 5 to 15 gamma (Explorer 10). Variations in the interplanetary field due to flares can increase intensities by as much as five times.

Furthermore, under solar flare conditions, solar magnetic effects penetrate more deeply into the earth's magnetosphere, affect the degree of ionization in the ionosphere, and cause magnetic storms at the earth's surface.

| *INTERPLANETARY MAGNETIC FIELD* |
| --- |
| ***STRENGTH*** <br> *5 – 15 GAMMA* |
| ***VARIATION*** <br> ***AS MUCH AS 5 TIMES DURING FLARE ACTIVITY*** |

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DATA
BOOK
FOR
ENVIRONMENTAL
TESTING
AND
SPACECRAFT
EVALUATION

# SECTION V

# THE LAUNCH ENVIRONMENT

INTRODUCTION

UNIT 1

VIBRATION
ACOUSTIC
TRANSIENT LOADS
ACCELERATION

# INTRODUCTION

The ability of a spacecraft to perform its designated mission depends, to a large extent, on its ability to survive the launch environments. Induced environments which critically influence spacecraft design are vibration, acoustic noise, shock, and acceleration. These environments occur primarily in combination at particular times in the launch phase.

The magnitude of the spacecraft environments are dependent on the characteristics of the launch vehicle used; that is, the vehicle thrust and distance of spacecraft from booster rocket engines. Thrust to weight ratio, spacecraft weight, free stream dynamic pressure, and the type of protective shroud also influence the magnitude of the induced shock, vibration, acoustic noise, and acceleration environments.

Vibration and acoustic environments are generally most severe at liftoff, during the transonic period, and during the maximum dynamic pressure period of the vehicle flight. Shock and acceleration environments are often severe at liftoff, staging, shroud ejection, and spacecraft separation.

Normally the structural designer requires the magnitudes and characteristics of these environments prior to spacecraft design. Furthermore, these data form the basis for development of realistic specifications for testing spacecraft and spacecraft components.

It is the intent of this section to present the nature and characteristics of these dynamic environments for current generation spacecraft.

# VIBRATION

The spacecraft receives vibration through mechanical and acoustical paths. Acoustically induced vibrations stem from the booster rocket engine noise and the aerodynamic boundary layer pressure fluctuations. Mechanically induced vibrations result from rocket engine thrust variation, resonant burning of upper stage solid propellant rockets, and apogee rocket motors.

## Acoustically Induced Vibration

Acoustically induced vibrations occur mainly in the frequency spectrum above 100 cps. These vibrations are characteristically broad band random and have high levels in frequencies up to several thousand cycles per second. Occasional ''periodicities'' may appear because of structural resonances in lightly damped structures. Generally speaking, the spacecraft vibration level above 100 cps is directly proportional to the acoustic sound pressure level.

Accoustically induced vibration data is presented in terms of power spectral density, $g^2$/cps, versus frequency since it is predominantly random. Figure 1 presents typical acoustic vibration spectra[1] (Ref. 1).

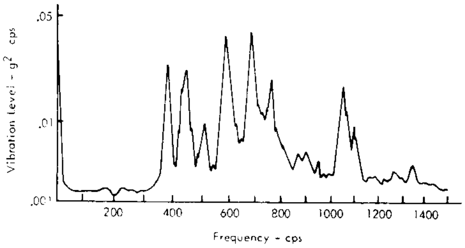


Figure 1. Vibration Level Due to Aerodynamic Noise Prior to Transonic Buffet - THOR AVT

### Liftoff

Figure 2 shows typical vibration time histories where the RMS vibration level is plotted against flight time. The vibration levels are severe at liftoff because of booster rocket engine noise and decrease rapidly shortly thereafter. This phenomenon occurs for several reasons. Just before liftoff the rocket engine is up to full thrust, and the flame deflector deflects the exhaust 90 degrees. Since the noise sources are distributed along the exhaust stream, they are closer to the spacecraft and result in higher vibration levels at liftoff than when the vehicle is airborne. In addition, ground reflection influences the noise level and the resultant spacecraft vibration levels at liftoff.

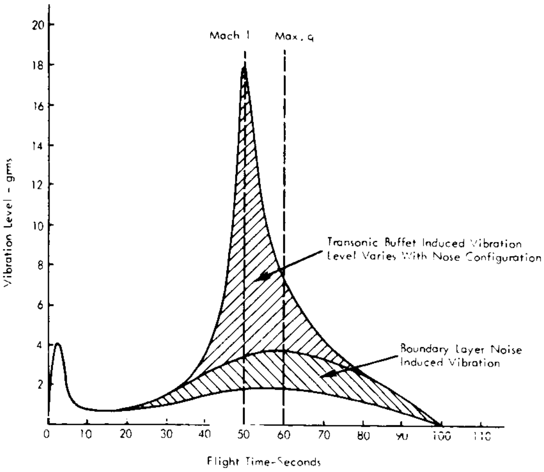


Figure 2. Typical Time History of Spacecraft Vibration Levels

### Flight

The spacecraft vibration level decreases rapidly just after liftoff. Then, as the vehicle gains speed, aerodynamic noise becomes the predominant source of spacecraft vibration, and, in general, the vibration level increases with time and as a function of the free stream dynamic pressure, q. The lower shaded area of Figure 2 shows that the spacecraft vibration level is maximum when q is maximum, and then approaches zero as the

[1] *Data from Application Vertical Test (AVT) launch with modified Thor in Echo Program.*

vehicle leaves the earth's atmosphere. The vibration level in the transonic-maximum q period of the vehicle trajectory is highly dependent on the payload shape. If the payload is of a streamlined, aerodynamically "clean" shape, the vibration levels are generally equal to or less than those experienced at launch. However, if the nose does not have a smooth configuration, extreme vibration levels will occur during the transonic and maximum q periods of flight. This situation is particularly true of the bulbous payload shape and shapes consisting of large blunted cone angles. Vibration levels on the order of 5 times the launch levels have been measured (Ref. 1). The upper shaded area of Figure 2 shows a typical time-history. Sometimes separate peaks show up for the Mach 1 and the maximum q periods of flight.

## Mechanically Induced Periodic Vibration

Spacecraft vibrations induced by mechanical means occur mainly in low frequencies. The significant vibrations generally involve the vehicle modal responses and are excited primarily by booster engine thrust perturbations.

Since vibration data usually have sinusoidal characteristics, passage of the raw data through narrow band filters gives a presentation in terms of peak g versus frequency. When sufficient data are available, statistical analysis makes possible the establishment of vibration levels in the low frequency portion of the vibration specification.

The two types of fuel used by launch vehicles, liquid and solid, produce differing vibrations.

### Liquid Propellant Vehicles

Virtually every large liquid rocket developed by the United States has experienced some form of vibrational instability. Measurements have shown high level longitudinal vibrations on Thor/Agena, Jupiter, Titan I and Titan II boosters. A coupled longitudinal instability on Titan II was of particular concern because of its possible effect on the country's space flight program (Ref. 2). In this case a strong axial vibration of the vehicle's entire structure occurred late in the first stage flight. The vibration apparently resulted from a regenerative feedback interaction between the vehicle's propulsion system and structural system. The insertion of simple hydraulic suppression devices into Stage I propellant feed lines solved the problem on Titan II. Reference 2 delineates this program, which has application to all liquid propellant vehicles.

The Thor-Agena B vehicle experiences this same longitudinal instability phenomenon (Reference 3). The vibration appears at about 30 seconds before main engine cutoff at a frequency of 17 cps and peaks at a level of approximately ±3 g at a frequency of 20 cps.

### Solid Propellant Vehicles

Solid rocket motors often induce high frequency oscillations which result from a combination of the acoustical characteristics of the combustion chamber and the fuel's burning properties. Several modes occur simultaneously with frequencies ranging from several hundred to several thousand cycles per second. The X-248 solid rocket (a small upper stage rocket) has been a primary offender in this category, producing extremely high spacecraft vibration levels, characteristically sinusoidal or combinations of several sinusoidals (Ref. 13). Current upper stage solid rockets (like X-258) produce a much less severe vibration environment because of design improvements (Ref. 4).

# ACOUSTIC FORCES

As stated in the section on vibration, there are two primary sources of noise which affect the spacecraft. The spacecraft receives high level noise from the launch vehicle engine and from aerodynamic boundary layer pressure fluctuations. Both are potential sources of structural fatigue and malfunctions. Figure 3 represents a typical time-history of the spacecraft noise environment. It follows the same general shape as the vibration environment and graphically demonstrates the fact that the random vibration results mainly from acoustic sources.

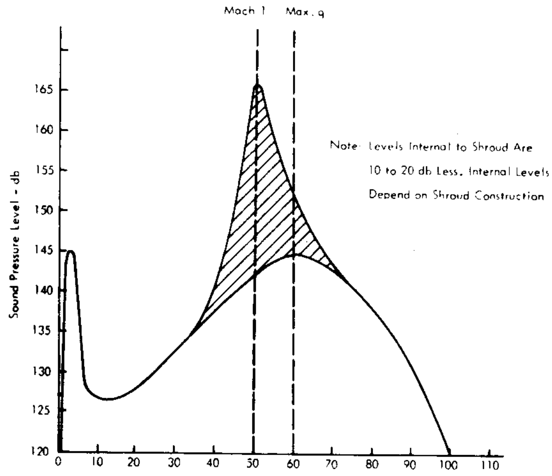


Figure 3. Typical Time History of External Acoustic Levels

## Launch Vehicle Engine

At liftoff the rocket engine noise is maximum. The sources of noise associated with the rocket exhaust are downstream from the nozzle exit plane. The noise is broadband random in nature and has maximum strength at an angle of 50 degrees from the direction of the exhaust. The frequency spectrum peak is a function of the exhaust nozzle diameter and the jet exit velocity. Total acoustic power radiated is between 0.5 and 1 percent of the mechanical exhaust stream power. Thor, Atlas, and Titan class boosters generate on the order of $10^7$ watts acoustic power. Typical sound pressure levels along the vehicle surface at liftoff vary from 160 db at the base to 140 db at the spacecraft. A few seconds after the vehicle is airborne, these levels drop by 15 to 20 db. This reduction results mainly from the change in direction of the noise as the exhaust jet turns from 90° off the vehicle's longitudinal axis to directly behind the vehicle. Figure 4 shows a typical octave band spectrum external to the spacecraft shroud.

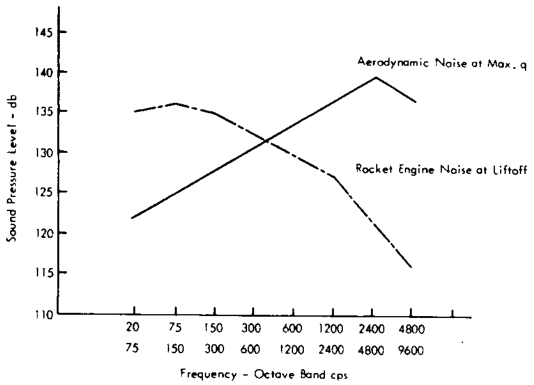


Figure 4. Typical Octave Spectra External to Spacraft - Shroud

## Aerodynamic Noise

As the vehicle gains speed, the aerodynamic noise becomes predominant and is most significant during the transonic and supersonic periods of flight. Transonic and maximum dynamic noise levels are a function of shroud configuration and the dynamic pressure. When streamlined, aerodynamic nose shapes are used, the noise level is generated by the the attached boundary layer and the acoustic pressure is approximately 0.5% of the free stream dynamic pressure. This relationship holds true in the subsonic low supersonic range according to some recent data obtained on the Scout vehicle (Ref. 5). Figure 3 depicts the time history of this relationship. Figure 4 shows a typical boundary layer noise spectrum at low supersonic flight maximum q. Note that the spectrum is flat up to 4000 cps and then rolls off. (A flat spectrum plotted on an octave band basis has a 3 db/octave slope). The peak in the octave band frequency spectrum occurs at higher frequencies as the Mach number increases.

### Shroud Configuration Effects

When non-streamlined aerodynamic shapes are encountered (e.g. like bulbous shrouds), flow separation occurs. This phenomenon occurs at area and shape transition sections where cone and cylinder sections must meet; the larger the cone angle the more severe the separated flow. Simular situations occur for flow over protuberances and on surfaces at a very high angle of attack. Flow separation results in certain distinctive phenomena. Maximum pressure fluctuations occur during transonic flight, and the energy is contained predominantly in the low and mid-frequency octave bands. Hence, the term transonic buffet has been employed in many instances. References 6, 7, 8, and 9 contain an abundance of wind tunnel data on various rocket-payload shapes. These reports disclose, in general, that the sound pressure level ranges from 1 to 20 percent of the free stream dynamic pressure; this is 6 db to 30 db higher than the boundary layer noise for the same q. Levels as high as 170 db can be experienced locally. More flight noise measurements are needed to verify these wind tunnel data. In addition, much must be learned about the spatial correlation properties of the pressures over the vehicle surface on a full scale basis. More information of this nature, plus structural response data, is required so that proper simulation of these noise sources can be accomplished in the laboratory.

## TRANSIENT LOADS

On a spacecraft, booster engine ignition, booster engine cut-off, stage separation, upper stage ignition and cut off, payload shroud ejection, and payload separation all impose shock loads. These are generally high level dynamic loads. Since they are transient, the resultant responses are those characteristic of the vehicle modes of vibration at the time the transient load occurs.

### Low Frequency

Transient longitudinal vehicle vibrations occur at liftoff. Figure 5 depicts a typical decaying sinusoidal vibration induced by the rapid thrust buildup and vehicle release at liftoff. At booster cut-off the spacecraft experiences similar transients. The spacecraft experiences similar phenomena as upper stages ignite and cut-off; obviously the modes of response are different since the vehicle configuration changes each time staging occurs.

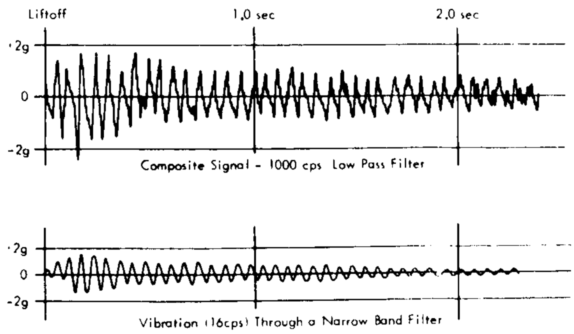


Figure 5. Typical Thrust Axis Vibration at Liftoff

Data from various Atlas boosted vehicles, particularly Ranger 5, indicate the existence of a transient torsional oscillation of 68 cps at the time of booster engine cut-off and sustainer engine cut-off events (Ref. 10). This oscillation is believed to result from combustion chamber pressure fluctuations. Two of the possible causes for these pressure fluctuations are: (1) coupling between one of the natural torsional modes of the vehicle and the thrust pertubations as in the case of the 20 cps longitudinal oscillations occurring in the Thor boosted vehicles (In this instance, the frequency of the driving torque would coincide with the vehicle frequency nearest 68 cps); (2) either random or periodic combustion chamber pressure fluctuations attributable to the combustion process (In this case, the driving torque would always be 68 cps for all vehicles).

These transient longitudinal and torsional vibrations dictate, in part, the low frequency test specification levels.

## High Frequency

Of the various shock sources, pyrotechnic devices, used in fairing separation and spacecraft-vehicle separation, generate the most severe shocks for local structures and components of the spacecraft. A shaped charge generally accomplishes fairing, separation; and explosive nuts usually accomplish vehicle-spacecraft separation.

The general characteristics of these shocks are that the shock is of a very short duration (less than one millisecond) and of a very high intensity (on the order of 1000g). Results of ground tests indicate that as the shock travels through the structure; it attenuates significantly with distance (Ref's. 11 and 12). Generally speaking the attenuation with distance follows the inverse square law.

Figure 6 shows typical shock response spectra near source (Ref. 11). These spectra describe the peak response of resonant parts located on the structure to the shock input. The abscissa represents the resonant frequency of such parts.

To date, there have been few spacecraft failures reported which can be directly attributed to these high level short duration shocks. However, Ref. 12 indicates that components, such as relays, chatter or change contact position, when subjected to these loads. These loads should certainly be considered and govern, in part, the choice of spacecraft components.

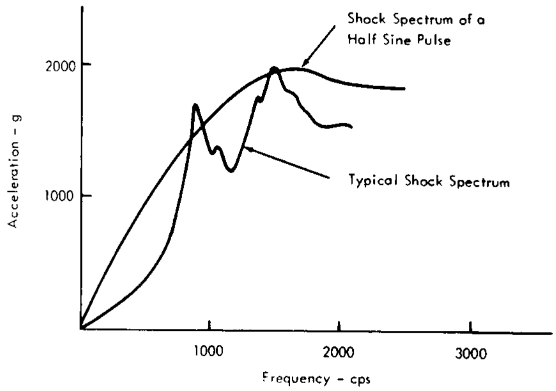

Figure 6. Typical Shock Spectrum Near Charge Due to Explosion of Pyrotechnic Devices

# ACCELERATION

## Thrust Acceleration

Figure 7 shows the envelope of maximum longitudinal acceleration experienced by unmanned spacecraft during the launch phase. Ref. 13 is the source of information on various launch vehicle acceleration profiles. Plotting of data from sounding rockets, and Scout, Delta, Thor-Agena, Atlas-Agena, and Centaur resulted in these curves. Figure 7 also presents estimated accelerations for future NASA launch vehicles like Saturn, Nova, Titan II and Titan III and of anticipated developments in solid and liquid rocket engines.

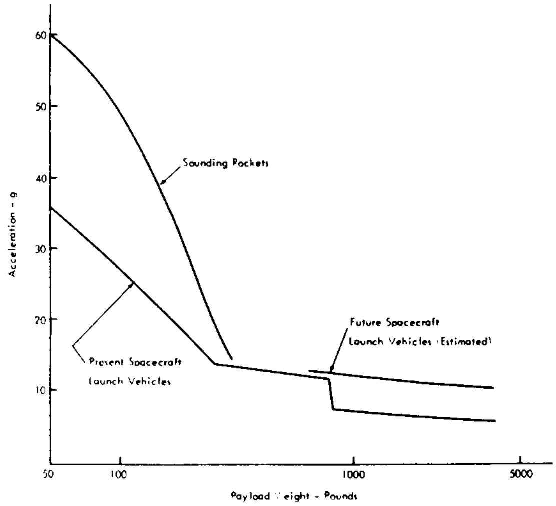


Figure 7. Envelope of Sounding Pocket and Spacecraft Maximum Acceleration During Launch Phase

Figure 8 and 9 show acceleration time histories for a Thor-Agena B launch vehicle with 1000 pound spacecraft and an Aerobee 300A sounding rocket with a 60 lb payload. The typical increase of acceleration with loss of fuel and the interruption from staging are evident. The Agena illustrates the unusual case of a long period of coasting flight, followed by a second firing of the rocket engines.

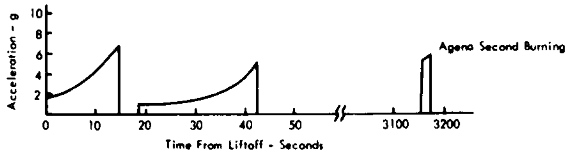


Figure 8. Thor-Agena B

Accelerations in the lateral directions during the launch phase are very low, normally less than 1.0 g.

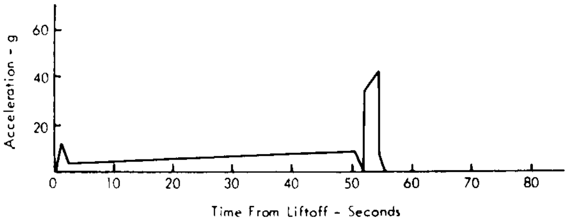


Figure 9. Aerobee 300 A

## Spin Acceleration

Those spacecraft which spin during the launch phase experience radial acceleration, proportional to the spin rate and radius. This acceleration may occur in conjunction with high longitudinal accelerations and vibration environments. Most sounding rockets have spin rates up to 300 to 600 rpm for payloads up to 300 lbs. (Ref. 13). Spacecraft up to the 500-600 lb. range on the Scout and Delta launch vehicles have spin rates of 150 to 180 rpm during last stage burning.

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# APPENDIXES

A

# GLOSSARY

# INTRODUCTION

This Glossary consists in part of selections from the *NASA Dictionary of Space Terms* (scheduled for publication in late 1962). In addition it contains terms especially applicable to environmental testing of spacecraft and spacecraft subsystems and components.

The Glossary has two purposes. It has the general purpose of providing a reference book for common space terms as well as for definitions which particularly apply to environmental test and evaluation activities. In this function it should be of considerable assistance in the orientation of new members of the Division.

The Glossary has the specific purpose of providing standardized definitions of terms, commonly used in specifications, reports, and memoranda which originate in the Test and Evaluation Division. By having a common reference book of terms available, it is believed that the task of achieving consistent terminology in Test and Evaluation Division publications will be facilitated.

# GLOSSARY

**Ablating Material.** – A material designed to dissipate heat by vaporizing or melting.

*Ablating materials are used on the surfaces of some reentry vehicles. Ablating materials absorb heat by increase in temperature and change in chemical or physical state. The heat is carried away from the surface by a loss of mass (liquid or vapor). The departing mass also blocks part of the convective heat transfer to the remaining material.*

**Ablation.** – The removal of surface material from a body by vaporization, melting, or other process; specifically the intentional removal of material from a nose cone or spacecraft during high-speed movement through a planetary atmosphere to provide thermal protection to the underlying structure. See **Ablating Material.**

**Abort.**– To cancel or cut short a flight, especially because of equipment failure.

**Absolute Altitude.** – Altitude above the actual surface of a planet or natural satellite, either land or water.

**Absolute Pressure.** – In engineering literature, a term used to indicate pressure above the absolute zero value corresponding to empty space as distinguished from 'gage pressure'.

In vacuum technology, 'pressure' always corresponds to absolute pressure, and therefore the term 'absolute pressure' is not required.

**Absolute Temperature.** – Temperature value relative to absolute zero.

**Absolute Zero.** – The theoretical temperature at which all molecular motion ceases.

*'Absolute zero' may be interpreted as the temperature at which the volume of a perfect gas vanishes, or more generally as the temperature of the cold source which would render a Carnot cycle 100 percent efficient. The value of absolute zero is now estimated to be $-273.16^{\circ}$Celsius (Centigrade), $-459.69^{\circ}$ Fahrenheit, $0^{\circ}$ Rankine.*

**Absorption.** – The process in which incident electromagnetic radiation is retained by a substance. A further process always results from absorption: that is, the irreversible conversion of the absorbed radiation into some other form of energy within and according to the nature of the absorbing medium. The absorbing medium itself may emit radiation, but only after an energy conversion has occurred.

**Acceleration.** – The rate of change of velocity.

*Decrease in velocity is sometimes called 'negative acceleration' or 'deceleration'.*

**Accelerometer.** – An instrument which measures acceleration or gravitational forces capable of imparting acceleration.

*An accelerometer usually uses a concentrated mass (seismic mass) which resists movement because of its inertia. The displacement of the seismic mass relative to its supporting frame or container is used as a measure of acceleration.*

**Acceptance.** – The act of an authorized representative of the government by which the government assents to ownership by it of existing and identified articles, or approves specific services rendered as partial or complete performance of the contract.

**Access Time.** – Of a computer, the time required under specified conditions to transfer information to or from storage, including the time required to communicate with the storage location.

**Accumulator.** – A device or apparatus that accumulates or stores up, as: 1. A contrivance is a hydraulic system that stores fluid under pressure. 2. A device sometimes incorporated in the fuel system of a gas-turbine engine to store up and release fuel under pressure as an aid in starting.

**Acoustic Excitation.** – Process of inducing vibration in a structure by exposure to sound waves.

**Acoustic Generator.** – Transducer which converts electric, mechanical, or other forms of energy into sound.

**Acoustic Velocity.** – The speed of propagation of sound waves. Also called 'speed of sound'.

**Acquisition.** – 1. The process of locating the orbit of a satellite or trajectory of a space probe so that tracking or telemetry data can be gathered. 2. The process of pointing an antenna or telescope so that it is properly oriented to allow gathering of tracking or telemetry data from a satellite or space probe.

**Actinic.** – Pertaining to electromagnetic radiation capable of initiating photochemical reactions, as in photography or the fading of pigments.

*Because of the particularly strong action of ultraviolet radiation on photochemical processes, the term has come to be almost synonymous with ultraviolet, as in 'actinic rays'.*

**Active.** – Transmitting a signal, as 'active satellite,' in contrast to 'passive'.

**Aerodynamic Vehicle.** – A device, such as an airplane, glider, etc., capable of flight only within a sensible atmosphere and relying on aerodynamic forces to maintain flight.

*This term is used when the context calls for discrimination from 'space vehicle'.*

**Aeronomy.** – 1. The study of the upper regions of the atmosphere where physical and chemical reactions due to solar radiation take place. 2. Science dealing with theories of planetary atmospheres.

**Aeropause.** – A region of indeterminate limits in the upper atmosphere, considered as a boundary or transition region between the denser portion of the atmosphere and space.

*From a functional point of view, it is considered to be that region in which the atmosphere is so tenuous as to have a negligible, or almost negligible, effect on men and aircraft, and in which the physiological requirements of man become increasingly important in the design of aircraft and auxiliary equipment.*

**Aerospace.** – (From aeronautics and space.) Of or pertaining to both the earth's atmosphere and space, as in 'aerospace industries'.

**Aerothermodynamic Border.** – An altitude at about 100 miles, above which the atmosphere is so rarefied that the motion of an object through it at high speeds generates no significant surface heat.

**Aerothermodynamics.** – The study of the aerodynamic and thermodynamic problems connected with aerodynamic heating.

**Afterbody.** – 1. A companion body that trails a satellite. 2. A section or piece of a rocket or missile that reenters the atmosphere unprotected behind the nosecone or other body that is protected for reentry. 3. The aft part of a vehicle.

**Agravic.** – Of or pertaining to a condition of no gravitation. See **Weightlessness.**

**Airglow.** – The quasi-steady radiant emission from the upper atmosphere as distinguished from the sporadic emission of the aurorae.

Airglow is a chemiluminescence due primarily to the emission of the molecules $O_2$ and $N_2$, the radical OH, and the atoms O and Na. It may be due to released latent energy from energy stored during daylight. Emissions observed in airglow could arise from 3-body atom collisions forming molecules, from 2-body reactions between atoms and molecules, or from recombination of ions.

Historically 'airglow' has referred to visual radiation. Some recent studies use 'airglow' to refer to radiation outside the visual range.

**Air Sounding.** – The act of measuring atmospheric phenomena or determining atmospheric conditions at altitude, especially by means of apparatus carried by balloons or rockets.

**Albedo.** – The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it, commonly expressed as a percentage. Compare Bond albedo.

The albedo is to be distinguished from the reflectivity, which refers to one specific wavelength (monochromatic radiation).

Usage varies somewhat with regard to the exact wavelength interval implied in albedo figures; sometimes just the visible portion of the spectrum is considered, sometimes the totality of wavelengths in the solar spectrum.

**Alpha Particle.** – (Symbol ${}_2He^4$.) A positively charged particle emitted from the nuclei of certain atoms during radioactive disintegration. The alpha particle has an atomic weight of 4 and a positive charge equal in magnitude to 2 electronic charges; hence it is essentially a helium nucleus (helium atom stripped of its two planetary electrons).

Alpha particles are important in atmospheric electricity as one of the agents responsible for atmospheric ionization. Minute quantities of radioactive materials such as radium, present in almost all soils and rocks, emit alpha particles and those which enter the surface air layer produce large numbers of ions along their short air paths. Alpha particles of average energy have a range of only a few centimeters in air, so radioactive matter in the earth cannot directly ionize the air above a height of a fraction of a meter. On the other hand, certain radioactive gases, such as radon and thoron, may be carried to heights of several kilometers (after initial formation during a radioactive disintegration of atoms of soil or rock matter) before emitting characteristic alpha particles which can then ionize air in the free atmosphere. The high density of ion pairs produced along the track of an alpha particle favors very rapid recombination (columnar recombination) that greatly reduces the effective ionization produced by these particles.

**Ambient.** – Specifically, pertaining to the environment about a flying aircraft or other body but undisturbed or unaffected by it, as in 'ambient air', or 'ambient temperature'.

**Amplidyne.** – A special type of dc generator used as a power amplifier, in which the output voltage responds to changes in field excitation; used extensively in servo systems.

**Analog Computer.** – A computing machine that works on the principle of measuring, as distinguished from counting, in which the input data are made analogous to a measurement continuum, such as voltages, linear lengths, resistances, light intensities, etc., which can be manipulated by the computer.

*Analog computers range from the relatively simple devices of the slide rule or airspeed indicator to complicated electrical machines used for solving mathematical problems.*

**Anechoic Chamber.** – An enclosure in which a sound field can be established without objectionable interference from sound reflections at its boundaries. Contrast with reverberation chamber.

**Angstrom.** – A unit of length, used chiefly in expressing short wavelengths. Ten billion angstroms equal one meter.

**Anomalistic Period.** – The interval between two successive perigee passes of a satellite in orbit about a primary. Also called 'perigee-to-perigee period.'

**Anomaly.** – 1. In general, a deviation from the norm. 2. In geodesy, a deviation of an observed value from a theoretical value, due to an abnormality in the observed quantity. 3. In celestial mechanics, the angle between the radius vector to an orbiting body from its primary (the focus of the orbital ellipse) and the line of apsides of the orbit, measured to the direction of travel, from the point of closest approach to the primary (perifocus).

The term defined above is usually called 'true anomaly', v, to distinguish it from the eccentric anomaly, E, which is measured at the center of the orbital ellipse, or from the mean anomaly, M, which is what the true anomaly would become if the orbiting body had a uniform angular motion.

**Aphelion.** – That orbital point farthest from the sun when the sun is the center of attraction. That point nearest the sun is called 'perihelion'.

The aphelion of the earth is $1.520 \times 10^{18}$ cm from the sun.

**Apogee.** – In an orbit about the earth, the point at which the satellite is farthest from the earth; the highest altitude reached by a sounding rocket.

**Apogee Rocket.** – A rocket attached to a satellite or spacecraft designed to fire when the craft is at apogee, the point farthest from the earth in orbit. The effect of the apogee rocket is to establish a new orbit farther from the earth or to allow the craft to escape from earth orbit.

**Arago Point.** – One of the three commonly detectable points along the vertical circle through the sun at which the degree of polarization of skylight goes to zero; a neutral point.

The Arago point, so named for its discoverer, is customarily located at about 20° above the antisolar point; but it lies at higher elevations in turbid air. The latter property makes the Arago distance a useful measure of atmospheric turbidity. Measurements of the location of this neutral point are typically more easily carried out than measurements of the Babinet point and the Brewster point, both of which lie so close to the sun (about 20° above and below the sun, respectively) that glare problems become serious.

**Arc-Jet Engine.** – A type of electrical rocket engine in which the propellant gas is heated by passing through an electric arc.

**Article.** – A unit of hardware or any portion thereof required by the contract.

**Artificial Antenna.** – A device which has the equivalent impedance characteristics of an antenna and the necessary power-handling capabilities, but which does not radiate nor intercept radiofrequency energy. Also called 'dummy antenna'.

**Artificial Gravity.** – A simulated gravity established within a space vehicle, as by rotating a cabin about an axis of a spacecraft, the centrifugal force generated being similar to the force of gravity.

**Assembly.** – An element of a component consisting of parts and/or subassemblies which performs functions necessary to the operation of the component as a whole. Examples are: pulsing networks, gyro assembly, oscillator assembly, etc.

**Asteroid.** – One of the many small celestial bodies revolving around the sun, most of the orbits being between those of Mars and Jupiter. Also called 'planetoid', 'minor planet'. See **Planet.**

*The term 'minor planet' is preferred by many astronomers but 'asteroid' continues to be used in astronomical literature, especially attributively, as in 'asteroid belt'.*

**Astro.** – A prefix meaning 'star' or 'stars' and, by extension, sometimes used as the equivalent of 'celestial', as in astronautics.

**Astroballistics.** – The study of the phenomena arising out of the motion of a solid through a gas at speeds high enough to cause ablation; for example, the interaction of a meteoroid with the atmosphere.

*Astroballistics uses the data and methods of astronomy, aerodynamics, ballistics, and physical chemistry.*

**Astrodynamics.** – The practical application of celestial mechanics, astroballistics, propulsion theory, and allied fields to the problem of planning and directing the trajectories of space vehicles.

**Astronaut.** – 1. A person who occupies a space vehicle. 2. Specifically one of the test pilots selected to participate in Project Mercury, the first United States program for manned space flight.

**Astronautics.** – 1. The art, skill, or activity of operating space vehicles. 2. In a broader sense, the science of space flight.

**Astronomical Unit (abbr AU).** – In the astronomical system of measures, a unit of length usually defined as the distance from the Earth to the Sun, approximately 92,900,000 statute miles or 149,600,000 kilometers. It is more precisely defined as the unit of distance in terms of which, in Kepler's Third Law, $n^2a^3 = k^2(1 + m)$, the semimajor axis a of an elliptical orbit must be expressed in order that the numerical value of the Gaussian constant, k, may be exactly 0.01720209895 when the unit of time is the ephemeris day.

In astronomical units, the mean distance of the Earth from the Sun, calculated by Kepler's law from the observed mean motion n and adopted mass m, is 1.00000003.

**Atmosphere.** – The envelope of air surrounding the earth; also the body of gases surrounding or comprising any planet or other celestial body.

**Atomic Clock.** – A precision clock that depends for its operation on an electrical oscillator (as a quartz crystal) regulated by the natural vibration frequencies of an atomic system (as a beam of cesium atoms or ammonia molecules).

**Attenuation.** – In physics, any process in which the flux density (or power, amplitude, intensity, illuminance, etc.) of a 'parallel beam' of energy decreases with increasing distance from the energy source. Attenuation is always due to the action of the transmitting medium itself (mainly by absorption and scattering). Losses from any divergence of the beam add to the attenuation loss.

The space rate of attenuation of electromagnetic radiation is described by Bouguer's law.

In meteorological optics, the attenuation of light is customarily termed 'extinction'. (The latter is sometimes used with regard to any electromagnetic radiation.)

**Attitude.** – The position or orientation of an aircraft, spacecraft, etc., either in motion or at rest, as determined by the relationship between its axes and some reference line or plane such as the horizon.

**Auger Shower.** – A very large cosmic-ray shower. Also called 'extensive air-shower'.

**Aurora.** – The sporadic visible emission from the upper atmosphere over middle and high latitudes. Also called 'northern lights'.

**Aurora Australia.** – The aurora of the Southern Hemisphere. See **Aurora.**

**Aurora Borealis.** – The aurora of northern latitudes. Also called 'aurora polaris', 'northern lights'. See **Aurora.**

**Axis.** – (pl. axes) 1. A straight line about which a body rotates, or around which a plane figure may rotate to produce a solid; a line of symmetry. 2. One of a set of reference lines for certain systems of coordinates.

**Azimuth.** – 1. Horizontal direction or bearing. Compare azimuth angle, bearing. 2. In navigation, the horizontal direction of a celestial point from a terrestrial point, expressed as the angular distance from a reference direction, usually measured from 000° at the reference direction clockwise through 360°.

**Azusa.** – A short range tracking system which gives space position and velocity of the object being tracked.

**Backout.** – An undoing of things already done during a countdown, usually in reverse order.

**Backup.** – 1. An item kept available to replace an item which fails to perform satisfactorily.

2. An item under development intended to perform the same general function performed by another item also under development.

**Balance.** – 1. The equilibrium attained by an aircraft, rocket, or the like when forces and moments are acting upon it so as to produce steady flight, especially without rotation about its axes; also used with reference to equilibrium about any specified axis, as, an airplane is balance about its longitudinal axis. 2. A weight that counterbalances something, especially, on an aircraft control surface, a weight installed forward of the hinge axis to counterbalance the surface aft of the hinge axis.

**Ballistics.** – The science that deals with the motion, behavior, and effects of projectiles, especially bullets, aerial bombs, rockets, or the like; the science or art of designing and hurling projectiles so as to achieve a desired performance.

**Ballistic Trajectory.** – The trajectory followed by a body being acted upon only by gravitational forces and the resistance of the medium through which it passes.

*A rocket without lifting surfaces is in a ballastic trajectory after its engines cease operation.*

**Bar.** – Unit of pressure equal to $10^6$ dyne per $cm^2$ ($10^6$ barye) 1000 millibars, 29.53 in. of Hg.

**Barye.** – Sometimes used by British to denote pressure unit of the cgs system of physical units, equal to one dyne per $cm^2$ (0.001 millibar). See **Microbar.**

**Beam.** – A ray or collection of focused rays of radiated energy, e.g., a beam of radio waves used as a navigation aid.

**Binary Notation.** – A system of positional notation in which the digits are coefficients of powers of the base 2 in the same way as the digits in the conventional decimal system are coefficients of powers of the base 10.

*Binary notation employs only two digits, 1 and 0, therefore is used extensively in computers where the 'on' and 'off' positions of a switch or storage device can represent the two digits.*
*In decimal notation* $111 = (1 \times 10^2) + (1 \times 10^1) + (1 \times 10^0) = 100 + 10 + 1 =$ *one hundred and eleven.*
*In binary notation* $111 = (1 \times 2^2) + (1 \times 2^1) + (1 \times 2^0) = 4 + 2 + 1 =$ *seven.*

**Bipropellant.** – A rocket propellant consisting of two unmixed or uncombined chemicals (fuel and oxidizer) fed to the combustion chamber separately.

**Bird.** – A colloquial term for a rocket, satellite, or spacecraft.

**Bit.** – (From binary digit.) A unit of information.

**Black Body (abbr b).** – 1. A hypothetical 'body' which absorbs all of the electromagnetic radiation striking it; that is, one which neither reflects nor transmits any of the incident radiation.

No actual substance behaves as a true black body, although platinum black and other soots rather closely approximate this ideal. However, one does speak of a black body with respect to a particular wavelength interval. This concept is fundamental to all of the radiation laws, and is to be compared with the similarly idealized concepts of the white body and the gray body. In accordance with Kirchoff's law, a black body not only absorbs all wavelengths, but emits at all wavelengths and does so with maximum possible intensity for any given temperature.

**Black Box.** – Colloquially, any unit, usually an electronic device such as an amplifier, which can be mounted in a rocket, spacecraft, or the like as a single package. See **Component.**

**Blackout.** – 1. A fadeout of radio communications due to environmental factors such as ionospheric disturbances, or a plasma sheath surrounding a reentry vehicle. 2. A condition in which vision is temporarily obscured by a blackness, accompanied by a dullness of certain of the other senses, brought on by decreased blood pressure in the head and a consequent lack of oxygen, as may occur in pulling out of a high-speed dive in an airplane.

**Blockhouse.** – (Also written 'block house'). A reinforced concrete structure, often built underground or partly underground, and sometimes dome-shaped, to provide protection against blast, heat, or explosion during rocket launchings or related activities; specifically, such a structure at a launch site that houses electronic control instruments used in launching a rocket.

**Boilerplate.** – As in ' boilerplate capsule', a metal copy of the flight model, the structure or components of which are heavier than the flight model.

**Boiloff.** – The vaporization of a cold propellant such as liquid oxygen or liquid hydrogen, as the temperature of the propellant mass rises as in the tank of a rocket being readied for launch.

**'Bola' Concept.** – Concept of a manned nuclear vehicle in which a long cable separates the manned platform from the reactor power system, with consequent reduction of biological hazard and the need for heavy shielding.

**Boltzmann's Constant.** – The ratio of the universal gas constant to Avogadro's number; equal to $1.3804 \times 10^{-16}$ ergs per degree K. Sometimes called 'gas constant per molecule', 'Boltzmann's universal conversion factor'.

**Bond Albedo.** – The ratio of the amount of light reflected from a sphere exposed to parallel light to the amount of light incident upon it. Sometimes shortened to 'albedo'.

The Bond albedo is used in planetary astronomy.

**Booster.** – Short for 'booster engine', 'booster rocket', or 'launch vehicle'.

**Booster Engine.** – An engine, especially a booster rocket, that adds its thrust to the sustainer engine.

**Booster Rocket.** – 1. A rocket engine, either solid or liquid fuel, that assists the normal propulsive system or sustainer engine of a rocket or aeronautical vehicle in some phase of its flight. 2. A rocket used to set a missile vehicle in motion before another engine takes over.

*In sense 2 the term 'launch vehicle' is more commonly used.*

**Boostglide Vehicle.** – A vehicle (half aircraft, half spacecraft) designed to fly to the limits of the sensible atmosphere, then be boosted by rockets into the space above, returning to earth by gliding under aerodynamic control.

**Bouguer's Law.** – A relationship describing the rate of decrease of flux density of a plane-parallel beam of monochromatic radiation as it penetrates a medium which both scatters and absorbs at that wavelength.

**Braking Ellipses.** – A series of ellipses, decreasing in size due to aerodynamic drag, followed by a spacecraft in entering a planetary atmosphere.

*In theory, this maneuver will allow a spacecraft to dissipate energy through aerodynamic heating without burning up.*

**Bremsstrahlung Effect.** – The emission of electromagnetic radiation as a consequence of the acceleration of charged elementary particles, such as electrons, under the influence of the attractive or repulsive force-fields of atomic nuclei near which the ambient, charged particle moves.

In cosmic-ray shower production, bremsstrahlung (in German, 'braking radiation') effects give rise to emission of gamma rays as electrons encounter atmospheric nuclei. The emission of radiation in the bremsstrahlung effect is merely one instance of the general rule that electromagnetic radiation is emitted only when electric charges undergo acceleration.

**British Thermal Unit (Btu).** – The amount of heat required to raise 1 pound of water at 60°F, 1°F. General usage makes 1 Btu equal 252 calories.

**Buffer.** – In computers: 1. An isolating circuit used to avoid reaction of a driven circuit on the corresponding driving circuit. 2. A storage device used to compensate for a difference in rate of flow of information or time on occurrence of events when transmitting information from one device to another.

**Burn.** – A period during which a rocket engine is firing, as in 'second burn' the second period during a flight in which the engine is firing.

**Burning Rate (abbr r).** – Velocity at which a solid propellant in a rocket is consumed, measured in a direction normal to the propellant surface and is usually expressed in inches per second.

**Burnout.** – 1. An act or instance of the end of fuel and oxidizer burning in a rocket; the time at which this burnout occurs. Compare cutoff. 2. An act or instance of something burning out or of overheating; specifically, an act or instance of a rocket combustion chamber, nozzle, or other part overheating so as to result in damage or destruction.

**Burst.** – 1. A single pulse of radio energy; specifically such a pulse at radar frequencies. 2. Solar radio burst. 3. Cosmic ray burst.

**Calorie.** – Originally amount of heat required to raise temperature of one gram of water through one degree centigrade (the gram-calorie), but a more precise expression is that a 15° gram-calorie (cal 15) is the amount of heat required to raise the temperature of one gram of water from 14.5°C to 15.5 °C and is equal to 4.1855 joules. General usage makes 1 Btu equal 252 calories.

**Capacity.** – In computer operations: 1. The largest quantity which can be stored, processed, or transferred. 2. The largest number of digits or characters which may be regularly processed. 3. The upper and lower limits of the quantities which may be processed.

**Capsule.** – 1. A boxlike component or unit, often sealed. 2. A small, sealed pressurized cabin with an internal environment which will support life in a man or animal during extremely high altitude flight, space flight, or emergency escape.

The term, 'spacecraft', is preferred to capsule for any man-carrying vehicle.

**Celestial Mechanics.** – The study of the theory of the motions of celestial bodies under the influence of gravitational fields.

**Celestial Sphere.** – An imaginary sphere of infinite radius concentric with the earth, on which all celestial bodies except the earth are assumed to be projected.

**Centrifuge.** – A mechanical device which applies centrifugal force to the test specimen by means of a long rotating arm to simulate very closely the prolonged accelerations encountered in high-performance aircraft, rockets, and spacecraft.

*The simulated acceleration or centrifugal force produced is proportional to the distance from the center of rotation and the square of the rotational velocity.*

**Characteristic.** – Any dimensional, visual, functional, mechanical, electrical, chemical, physical, or material feature or property; and any process-control element which describes and establishes the design, fabrication, and operating requirements of an article.

**Checkout.** – 1. A sequence of actions taken to test or examine a thing as to its readiness for incorporation into a new phase of use, or for the performance of its intended function. 2. The sequence of steps taken to familiarize a person with the operation of an airplane or other piece of equipment.

In sense 1, a checkout is usually taken at a transition point between one phase of action and another. To shorten the time of checkout, automation is frequently employed.

**Cheese Antenna.** – A cylindrical parabolic reflector enclosed by two plates perpendicular to the cylinder, so spaced as to permit the propagation of more than one mode in the desired direction of polarization. It is fed on the focal line.

**Chemical Fuel.** – 1. A fuel that depends upon an oxidizer for combustion or for development of thrust, such as liquid or solid rocket fuel or internal-combustion-engine fuel; distinguished from nuclear fuel. 2. A fuel that uses special chemicals, such as a boron-based fuel.

**Chemical Rocket.** – A rocket using chemical fuel, fuel which requires an oxidizer for combustion, such as liquid or solid rocket fuel.

**Chemosphere.** – The vaguely defined region of the upper atmosphere in which photochemical reactions take place. It is generally considered to include the stratosphere (or the top thereof) and the mesosphere, and sometimes the lower part of the thermosphere.

This entire region is the seat of a number of important photochemical reactions involving atomic oxygen O, molecular oxygen $O_2$, ozone $O_3$, hydroxyl OH, nitrogen $N_2$, sodium Na, and other constituents to a lesser degree.

**Chugging.** – A form of combustion instability, especially in a liquid-propellant rocket engine, characterized by a pulsing operation at a fairly low frequency, sometimes defined as occurring between particular frequency limits; the noise made in this kind of combustion. Also called 'chuffing'.

**Cislunar.** – (Latin cis 'on this side'). Of or pertaining to phenomena, projects, or activity in the space between the earth and moon, or between the earth and the moon's orbit.

**Combustion Resonance.** – The sinusoidal vibration of high g level induced by uneven pressures which occur within the combustion chamber of a solid fuel rocket engine. See **Sinusoidal Vibration** and **Random Vibration.**

*In spacecraft testing, this environment is simulated by sweeping sinusoidal vibration over a narrow frequency band to include the frequency at which the spacecraft will experience combustion resonance.*

**Combustion Resonance Dwell** = **Combustion Resonance.**

**Comet.** – A luminous member of the solar system composed of a head or coma at the center of which a presumably solid nucleus is sometimes situated, and often with a spectacular gaseous tail extending a great distance from the head.

*The orbits of comets are highly elliptical.*

**Component.** – A self-contained combination of parts and/or assemblies within a subsystem performing a function necessary to the subsystem's operation. Examples are: receivers, transmitters, modulators, etc.

**Console.** – An array of controls and indicators for the monitoring and control of a particular sequence of actions, as in the checkout of a rocket, a countdown action, or a launch procedure.

*A console is usually designed around desklike arrays. It permits the operator to monitor and control different activating instruments, data recording instruments, or event sequencers.*

**Constellation.** – Originally a conspicuous configuration of stars; now a region of the celestial sphere marked by arbitrary boundary lines.

**Contractor.** – The individual(s) or concern(s) who enter into a prime contract with the government.

**Control.** – Specifically, to direct the movements of an aircraft, rocket, or spacecraft with particular reference to changes in altitude and speed. Contrast guidance.

**Control Rocket.** – A vernier engine, retrorocket, or other such rocket, used to guide or make small changes in the velocity of a rocket, spacecraft, or the like.

**Coriolis Acceleration.** – An acceleration of a particle moving in a (moving) relative coordinate system. The total acceleration of the particle, as measured in an internal coordinate system, may be expressed as the sum of the acceleration within the relative system, the acceleration of the relative system itself, and the coriolis acceleration.

In the case of the earth, moving with angular velocity $\Omega$, a particle moving relative to the earth with velocity V has the coriolis acceleration $2\Omega \times V$. If Newton's laws are to be applied in the relative system, the coriolis acceleration and the acceleration of the relative system must be treated as forces. See **Gravity.**

**Corona.** – 1. The faintly luminous outer envelope of the sun. Also called 'solar corona.'

*The corona can be observed at the earth's surface only at solar eclipse or with the coronagraph, a photographic instrument which artificially blocks out the image of the body of the sun.*

2. Discharge of electricity which occurs at the surface of a conductor under high voltage. The phenomena is dependent on ambient pressure of the gas surrounding the conductor.

*Since phenomenon is enhanced by reduced pressure, tests must be conducted to verify that no significant corona exists within the spacecraft or its components under anticipated conditions.*

**Cosmic Rays.** – The aggregate of extremely high energy subatomic particles which bombard the atmosphere from outer space. Cosmic ray primaries seem to be mostly protons, hydrogen nuclei, but also comprise heavier nuclei. On colliding with atmospheric particles they produce many different kinds of lower-energy secondary cosmic radiation. Also called 'cosmic radiation.'

The maximum flux of cosmic rays, both primary and secondary, is at an altitude of 20 km, and below this the absorption of the atmosphere reduces the flux, though the rays are still readily detectable at sea level. Intensity of cosmic ray showers has also been observed to vary with latitude, being more intense at the poles.

**COSPAR.** – Abbreviation for 'Committee on Space Research', International Council of Scientific Unions.

**Coulomb Damping.** – Also called dry friction damping. The dissipation of energy that occurs when a particle in a vibrating system is resisted by a force whose magnitude is a constant independent of displacement and velocity, and whose direction is opposite to the direction of the velocity of the particle.

**Countdown.** – The time period in which a sequence of events is carried out to launch a rocket; the sequence of events.

**Cryogenic Propellant.** – A rocket fuel, oxidizer, or propulsion fluid which is liquid only at very low temperatures.

**Cryogenic Temperature.** – In general, a temperature range below about -50°C; more particularly, temperatures within a few degrees of absolute zero.

**Cutoff.** – An act or instance of shutting something off; specifically in rocketry, and act or instance of shutting off the propellant flow in a rocket, or of stopping the combustion of the propellant.

**Damping.** – The dissipation of energy with time and distance.

**Data Reduction.** – Transformation of observed values into useful, ordered, or simplified information.

**Debug.** – 1. To isolate and remove malfunctions from a device, or mistakes from a computer routine or program. 2. Specifically, in electronic manufacturing, to operate equipment under specified environmental and test conditions in order to eliminate early failures and to stabilize equipment prior to actual use.

**Deceleration.** – 1. The act or process of moving with decreasing speed; the state of so moving. Synonymous with negative acceleration.

**Decibel (abbr db).** – A unit which denotes the magnitude of a quantity with respect to an arbitrarily established reference value of the quantity, in terms of the logarithm (to the base 10) of the ratio of the quantities.

*For example, in electrical transmission circuits, a value of power may be expressed in terms of a power level in decibels; the power level is given by 10 times the logarithm (to the base 10) of the ratio of the actual power to a reference power (which corresponds to 0 db).*

**Deep Space Net.** – A combination of three radar and communications stations in the United States, Australia, and South Africa so located as to keep a spacecraft in deep space under observation at all times.

**Deep Space Probes.** – Spacecraft designed for exploring space to the vicinity of the moon and beyond. Deep space probes with specific missions may be referred to as 'lunar probe', 'Mars probe', 'solar probe', etc.

**Degradation.** – Gradual deterioration in performance.

**Degrees-of-Freedom.** – The number of degrees-of-freedom of a mechanical system is equal to the minimum number of independent coordinates required to define completely the positions of all parts of the system at any instant. In general, it is equal to the number of independent displacements that are possible.

**Delay.** – The time (or equivalent distance) displacement of some characteristic of a wave relative to the same characteristic of a reference wave; that is, the difference in phase between the two waves.

In one-way radio propagation, for instance, the phase delay of the reflected wave over the direct wave is a measure of the extra distance traveled by the reflected wave in reaching the same receiver.

**Design Engineering Tests.** – Environmental tests having the purpose of trying certain design features prior to finalizing design for Design Qualification Tests. For instance the structural model of the spacecraft is subjected to certain environmental exposures or Design Engineering Tests up to design qualification level in order to establish confidence in its structural design.

**Design Qualification Tests.** – Series of environmental and other tests applied to prototype spacecraft, subsystems, components, or experiments to determine if design meets requirements for launch and flight of spacecraft. These tests are planned to subject spacecraft to considerably greater rigors of environment than expected during launch and flight in order to achieve maximum design reliability.

**Destruct.** – The deliberate action of destroying a rocket vehicle after it has been launched, but before it has completed its course.

*Destructs are executed when the rocket gets off its plotted course or functions in such a way as to become a hazard.*

**Deviation.** – 1. In NASA quality control, specific authorization, granted before the fact, to depart from a particular requirement of specifications or related documents. 2. In statistics, the difference between two numbers. Also called 'departure'. It is commonly applied to the difference of a variable from its mean, or to the difference of an observed value from a theoretical value.

**Digital Computer.** – A computer which operates on the principle of counting as opposed to measuring. See **Analog Computer.**

**Diplexer.** – A device permitting an antenna system to be used simultaneously or separately by two transmitters. Compare with duplexer.

**Dish.** – A parabolic type of radio or radar antenna, roughly the shape of a soup bowl.

**Displacement.** – A vector quantity that specifies the change of position of a body or particle and is usually measured from the mean position or position of rest. In general, it can be represented as a rotation vector or a translation vector, or both.

**Display.** – The graphic presentation of the output data of a device or system as, for example, a radar scope.

**Docking.** – The process of bringing two spacecraft together while in space.

**Doppler Shift.** – The change in frequency with which energy reaches a receiver when the source of radiation or a reflector of the radiation and the receiver are in motion relative to each other. The Doppler shift is used in many tracking and navigation systems.

**Dosimeter.** – A device, worn by persons working around radioactive material, which indicates the amount (dose) of radiation to which they have been exposed.

**Dovap.** – From Doppler, velocity and position, a tracking system which uses the Doppler shift caused by a target moving relative to a ground transmitter to obtain velocity and position information.

**Drogue Parachute.** – A type of parachute attached to a body, used to slow it down; also called 'deceleration parachute', or 'drag parachute'.

**Duplexer.** – A device which permits a single antenna system to be used for both transmitting and receiving.

*'Duplexer' should not be confused with 'diplexer', a device permitting an antenna system to be used simultaneously or separately by two transmitters.*

**Dynamic Balance.** – A condition in which the rotation of a spacecraft about a spin axis produces no net induced transverse torque. In dynamically balancing a spacecraft during environmental testing, weights are added or shifted to attain a close approximation of this condition while the spacecraft is being rotated. Contrast with static balance.

**Dynamic Pressure.** – Symbol q. 1. The pressure exerted by a fluid, such as air, by virtue

of its motion, equal to one half the fluid density times the fluid velocity squared $\frac{1}{2}\rho V^2$.
2. The pressure exerted on a body, by virtue of its motion through a fluid, for example, the pressure exerted on a rocket moving through the atmosphere.

**Dynamic Test Unit.** – A dynamic mock-up of the spacecraft which is subjected to such functional tests as spin-up, despin, boom and/or paddle erection, etc.

**Dyne (abbr d).** – That unbalanced force which acting for 1 second on body of 1 gram mass produces a velocity change of 1 cm/sec.
The dyne is the unit of force in the cgs system.

**Eccentric.** – Not having the same center; varying from a circle, as in 'eccentric orbit'.

**Ecliptic.** – The apparent annual path of the sun among the stars; the intersection of the plane of the earth's orbit with the celestial sphere.

*This is a great circle of the celestial sphere inclined at an angle of about 23°27′ to the celestial equator.*

**Ecological System.** – A habitable environment, either created artificially, such as in a manned space vehicle, or occurring naturally, such as the environment on the surface of the earth, in which man, animals, or other organisms can live in mutual relationship with each other.

*Ideally, the environment furnishes the sustenance for life, and the resulting waste products revert or cycle back into the environment to be used again for the continuous support of life.*

**Effective Atmosphere.** – That part of the atmosphere which effectively influences a particular process or motion, its outer limits varying according to the terms of the process or motion considered.
For example, an earth satellite orbiting at 250 miles altitude remains within the ionosphere, but because the air particles are so rare at this altitude as to cause no appreciable friction or deflection, the satellite may be considered to be outside the effective atmosphere. For movement of air vehicles the effective atmosphere ends at the aeropause (which see).

**Ejection Capsule.** – 1. In an aircraft or manned spacecraft, a detachable compartment serving as a cockpit or cabin, which may be ejected as a unit and parachuted to the ground. 2. In an artificial satellite, probe, or unmanned spacecraft, a boxlike unit usually containing recording instruments or records of observed data, which may be ejected and returned to earth by a parachute or other deceleration device.

**Electric Propulsion.** – The generation of thrust for a rocket engine involving acceleration of a propellant by some electrical device such as an arc jet, ion engine, or magnetohydrodynamic accelerator.

**Electromagnetic Radiation.** – Energy propagated through space or through material media in the form of an advancing disturbance in electrical and magnetic fields existing in space or in the media. Also called simply 'radiation'. See **Visible Radiation.**

*The earth's atmosphere is generally opaque to electromagnetic radiation although several 'windows' exist, notably one in the visible and one in the infrared portion of the electromagnetic spectrum where the atmosphere is transparent to electromagnetic radiation.*

**Electron.** – The subatomic particle that possesses the smallest possible electric charge.

*The term 'electron' is usually reserved for the orbital particle whereas the term 'beta particle' refers to a particle of the same electric charge inside the nucleus of the atom.*

**Electronic Data Processing.** – The use of electronic devices and systems in the processing of data so as to interpret the data and put it into usable form.

**Ellipse.** – A plane curve constituting the locus of all points the sum of whose distances from two fixed point called 'foci' is constant; an elongated circle.

*The orbits of planets, satellites, planetoids, and comets are ellipses; center of attraction is at one focus.*

**Emissivity.** – 1. The ratio of the emittance of a given surface at a specified wavelength and emitting temperature to the emittance of an ideal black body at the same wavelength and temperature. Sometimes called 'emissive power'.

The greatest value that an emissivity may have is unity, the least value zero. It is a corollary of Kirchhoff's law that the emissivity of any surface at a specified temperature and wavelength is exactly equal to the absorptivity of that surface at the same temperature and wavelength. The spectral emissivity is for a definite wavelength. The total emissivity is for all wavelengths.

2. (abbr $\epsilon$) Specifically, the ratio of the flux emitted by a clean, perfectly polished surface of the material to the flux that would have been emitted by a black body at the same temperature.

**End Item.** – A space system or any of its principal system or subsystem elements, e.g., launch vehicle, spacecraft, ground support system, propulsion engine, or guidance system. Also, articles covered by major subcontracts where NPC 200-2 is invoked by the NASA installation or by a system prime contractor. Also, articles which will be delivered direct to a government installation or provided as Government Furnished Property to a contractor.

**Environment.** – An external condition or the sum of such conditions, in which a piece of equipment or a system operates, as in 'temperature environment', 'vibration environment', or 'space environment'.

*Environments are usually specified by a range of values, and may be either natural or artificial.*

**Ephemeris.** – Any tabular statement of the assigned places of a celestial body for regular intervals; hence, the orbital characteristics of a man-made satellite are called its ephemeris.

**Epoch.** – A particular instant for which certain data are valid.

**Equalization.** – Used to describe the process of adjusting the input to a vibration exciter to conform with a specified frequency spectrum.

*In the random vibration phase of spacecraft environmental testing, completion of this process prior to test operations is necessary to assure that the spacecraft will receive the specified exposure.*

**Escape Velocity.** – The radial speed which a particle or larger body must attain in order to escape from the gravitational field of a planet or star.

*The escape velocity from Earth is approximately 7 miles per sec.; from Mars, 3.2 miles per sec.; and from the Sun, 390 miles per sec. In order for a celestial body to retain an atmosphere for astronomically long periods of time, the mean velocity of the atmospheric molecules must be considerably below the escape velocity.*

**Exosphere.** – The outermost, or topmost portion of the atmosphere.

*In the exosphere, the air density is so low that the mean free path of individual particles depends upon their direction with respect to the local vertical, being greatest for upward moving particles. It is only from the exosphere that atmospheric gases can, to any appreciable extent, escape into outer space.*

**Exotic Fuel.** – Any fuel considered to be unusual, as a boron-based fuel.

**Experiment.** – A combination of two or more components, including both the sensor and associated electronics, designed for acquisition of data for space research.

**Explosive Bolt.** – A bolt incorporating an explosive which can be detonated on command, thus destroying the bolt. Explosive bolts are used, for example, in separating a satellite from a rocket.

**Extraterrestrial.** – From outside the earth.

**Extraterrestrial Radiation.** – In general, solar radiation received outside the earth's atmosphere.

**Fatigue.** – A weakening or deterioration of metal or other material, or of a member, occurring under load, especially under repeated, cyclic, or continued loading.

**Field.** – A region of space at each point of which a given physical quantity has some definite value, thus a 'gravitational field', an 'electric field', a 'magnetic field', etc.

**Fixed Satellite.** – An earth satellite that orbits from west to east at such a speed as to remain constantly over a given place on the earth's equator.

**Flare.** – A bright eruption from the sun's chromosphere.

*Flares may appear within minutes and fade within an hour. They cover a wide range of intensity and size, and they tend to be associated with sunspots.*

*Flares are related to radio fadeouts and terrestrial magnetic disturbances.*

**Flight.** – Describes or pertains to travel of spacecraft or stages after liftoff. Thus, in testing, designates spacecraft or element thereof which is to be launched as distinct from structural model and prototype spacecraft which are test specimens only.

**Flight Acceptance Tests.** – The environmental and other tests which spacecraft scheduled for flight must pass before launch. These tests are planned to approximate expected environmental conditions and have the purpose of detecting flaws in material and workmanship. Tests given components/experiments before their incorporation into flight unit.

**Flight Unit.** – Spacecraft which is undergoing or has passed Flight Acceptance Tests (environmental and other tests) which qualify it for launch and space flight.

**Flux.** – The rate of flow of some quantity, often used in reference to the flow of some form of energy. Also called 'transport'. In nuclear physics generally, the number of radioactive particles per unit volume times their mean velocity.

**Flux Density.** – The flux (rate of flow) of any quantity, usually a form of energy, through a unit area of specified surface. (Note that this is not a volumetric density like radiant density.)

The flux density of electromagnetic radiation in general often is preferably specified as 'radiant flux density' or 'irradiance' in order to distinguish it from the slightly different concept of luminous flux density or illuminance. In radar, flux density commonly is referred to as power density. It is essential to understand that the flux density of radiation is in no sense a vector quantity, because it is the sum of the flux corresponding to all ray directions incident upon one 'side' of the unit area.

**Forced Vibration.** – The oscillation of a body in which the response is imposed by the excitation. If the excitation is periodic and continuing, the oscillation is steady-state.

**Free Fall.** – The fall or drop of a body, such as a rocket not guided, not under thrust, and not retarded by a parachute or other braking device.

**Free Vibration.** – Oscillation in the absence of forced vibration. The frequency of this oscillation is known as the body's natural frequency. See **Forced Vibration** and **Natural Frequency.**

**g or G.** – An acceleration equal to the acceleration of gravity, approximately 32.2 feet per second per second at sea level. By extension is commonly used as a unit of force which would impart acceleration equal to that of gravity. By international agreement, the value 980.665 cm/sec$^2$ or 32.1739 ft/sec$^2$ has been chosen as the standard acceleration of gravity.

**GSE.** – See **Ground Support Equipment.**

**Gamma Ray.** – A quantum of electromagnetic radiation emitted by a nucleus, each such photo being emitted as the result of a quantum transition between two energy levels of the nucleus. Gamma rays have energies usually between 10 kev and 10 Mev, with correspondingly short wavelengths and high frequencies. Also called 'gamma radiation'.

**Gantry.** – A frame structure that spans over something, as an elevated platform that runs astride a work area, supported by wheels on each side; specifically, short for 'gantry crane' or 'gantry scaffold'.

**Gantry Scaffold.** – A massive scaffolding structure mounted on a bridge or platform supported by a pair of towers or trestles that normally run back and forth on parallel tracks, used to assemble and service a large rocket on its launching pad. Often shortened to 'gantry'. Also called 'service tower'.

*This structure is a latticed arrangement of girders, tubing, platforms, cranes, elevators, instruments, wiring, floodlights, cables, and ladders-all used to attend the rocket.*

**Garbage.** – Miscellaneous objects in orbit, usually material ejected or broken away from a launch vehicle or satellite.

**Gas Cap.** – The gas immediately in front of a meteoroid or reentry body as it travels through the atmosphere; the leading portion of a meteor. This gas is compressed and adiabatically heated to incandescence.

**Gaussian Distribution.** – The probability distribution most frequently encountered in nature; e.g., the odds of getting various proportions of heads and tails in a series of trials. See **Random Vibration.**

*In a randomly vibrating system such as used in spacecraft environmental testing, the Gaussian Distribution is believed to best represent the distribution of accelerations.*

**Generation.** – In any technical or technological development, as of a missile, jet engine, or the like, a stage or period that is marked by features or performances not marked, or existent, in a previous period of development or production, as in 'second generation rocket'.

**Geo.** – A prefix meaning 'earth', as in 'geology', 'geophysics'.

*Most writers use the established terms such as 'geology' to refer to the same concept on other bodies of the solar system, as 'the geology of Mars', rather than 'areology' or 'marsology', 'geology of the moon', rather than 'selenology'.*

**Geocentric.** – Relative to the earth as a center; measured from the center of the earth.

**Geodetic.** – Pertaining to geodesy, the science which deals with the size and shape of the earth.

**Geomagnetism.** – The magnetic phenomena, collectively considered, exhibited by the earth.

**Geophysics.** – The physics of the earth and its environment, i.e., earth, air, and (by extension), space.

*Classically, geophysics is concerned with the nature of physical occurrences at and below the surface of the earth including, therefore, geology, oceanography, geodesy, seismology, hydrology, etc. The trend is to extend the scope of geophysics to include meteorology, geomagnetism, astrophysics, and other sciences concerned with the physical nature of the universe.*

**Geopotential.** – The potential energy of a unit mass relative to sea level, numerically equal to the work that would be done in lifting the unit mass from sea level to the height at which the mass is located; commonly expressed in terms of dynamic height or geopotential height.

**Geoprobe.** – A rocket vehicle designed to explore space near the earth at a distance of more than 4,000 miles from the earth's surface. Rocket vehicles operating lower than 4,000 miles are termed 'sounding rockets'.

**Giga.** – A prefix meaning multiplied by one billion.

**Gimbal.** – 1. A device with two mutually perpendicular and intersecting axes of rotation, thus giving free angular movement in two directions, on which an engine or other object may be mounted. 2. In a gyro, a support which provides the spin axis with a degree-of-freedom.

**Gox.** – Gaseous oxygen.

**Grain.** – An elongated molding or extrusion of solid propellant for a rocket, regardless of size.

**Gram.** – 1. Unit of weight in metric system; 453.6 grams equal 1 pound. 2. Unit of mass, 1 gram is the mass to which an acceleration of 1 cm/sec$^2$ is imparted by 1 dyne of force.

**Gravitation.** – The acceleration produced by the mutual attraction of two masses, directed along the line joining their centers of mass, and of magnitude inversely proportional to the square of the distance between the two centers of mass.

**Gravity.** – The force imparted by the earth to a mass on, or close to the earth. Since the earth is rotating, the force observed as gravity is the resultant of the force of gravitation and the centrifugal force arising from this rotation.

**Ground Support Equipment (GSE).** – Any ground-based equipment used for launch, checkout, or in-flight support of a space project.

**Guidance.** – The process of directing the movements of an aeronautical vehicle or space vehicle, with particular reference to the selection of a flight path. See **Control.**

In preset guidance a predetermined path is set into the guidance mechanism and not altered, in inertial guidance accelerations are measured and integrated within the craft, in command guidance the craft responds to information received from an outside source. Beam-rider guidance utilizes a beam, terrestrial-reference guidance some influence of the earth, celestial guidance the celestial bodies and particularly the stars, and homing guidance information from the destination. In active homing guidance the information is in response to transmissions from the craft, in semiactive homing guidance the transmissions are from a source other than the craft, and in passive homing guidance natural radiations from the destination are utilized. Mid-course guidance extends from the end of the launching phase to an arbitrary point enroute and terminal guidance extends from this point to the destination.

**Gyro.** – A device which utilizes the angular momentum of a spinning rotor to sense angular motion of its base about one or two axes at right angles to the spin axis. Also called 'gyroscope'.

**Hall Effect.** – The electrical polarization of a horizontal conducting sheet of limited extent, when that sheet moves laterally through a magnetic field having a component vertical to the sheet.

The Hall effect is important in determining the behavior of the electrical currents generated by winds in the lower ionosphere, since these winds advect the ionized layers across the earth's magnetic field and produce a complex electrical current system in the ionosphere. This current system in turn produces small changes in the earth's magnetic field as measured at the surface.

**Harmonic Response.** – The periodic response of a vibrating system, exhibiting the characteristics of resonance at a frequency that is a multiple of the excitation frequency.

**Heat Exchanger.** – A device for transferring heat from one fluid to another without intermixing the fluids. A regenerator is an example.

**Heat Shield.** – Any device that protects something from heat.

**Heat Sink.** – 1. In thermodynamic theory, a means by which heat is stored, or is dissipated or transferred from the system under consideration. 2. A place toward which the heat moves in a system. 3. A material capable of absorbing heat; a device utilizing such a material and used as a thermal protection device on a spacecraft or reentry vehicle. 4. In nuclear propulsion, any thermodynamic device, such as a radiator or condenser, that is designed to absorb the excess heat energy of the working fluid. Also called 'heat dump'.

**Heterosphere.** – The upper portion of a two-part division of the atmosphere according to the general homogeneity of atmospheric composition; the layer above the homosphere. The heterosphere is characterized by variation in composition, and mean molecular weight of constituent gases.

This region starts at 80 to 100 km above the earth, and therefore closely coincides with the ionosphere and the thermosphere.

**Hold.** – During a countdown: To halt the sequence of events until an impediment has been removed so that the countdown can be resumed, as in 'T minus 40 and holding'.

**Homosphere.** – The lower portion of a two-part division of the atmosphere according to the general homogeneity of atmospheric composition; opposed to the heterosphere. The region in which there is no gross change in atmospheric composition, that is, all of the atmosphere from the earth's surface to about 80 or 100 km.

The homosphere is about equivalent to the neutrosphere, and includes the troposphere, stratosphere, and mesosphere, and also the ozonosphere and at least part of the chemosphere.

**Hot Test.** – A propulsion system test conducted by actually firing the propellants.

**Hunting.** – Fluctuation about a midpoint due to instability, as oscillations of the needle of an instrument about a median value.

**Igniter.** – Any device used to begin combustion, such as a spark plug in the combustion chamber of a jet engine, or a squib used to ignite fuel in a rocket.

**Impact Area.** – The area in which a rocket strikes the earth's surface.

*Used specifically in reference to the 'impact area' of a rocket range.*

**Inertial Guidance.** – Guidance by means of acceleration measured and integrated within the craft.

**Infrared Radiation (abbr IR).** – Electromagnetic radiation lying in the wavelength interval from about 0.8 microns to an indefinite upper boundary sometimes arbitrarily set at 1,000 microns (0.01 cm). Also called 'black light', 'long wave radiation'.

At the lower limit of this interval, the infrared radiation spectrum is bounded by visible radiation, while on its upper limit it is bounded by microwave radiation of the type important in radar technology.

Whereas visible radiation is generated primarily by intra-atomic processes, infrared radiation is generated almost wholly by larger-scale intra-molecular processes, chiefly molecular rotations and internal vibrations of many types. Electrically symmetric molecules, such as the nitrogen and oxygen molecules which comprise most of the earth's atmosphere, are not capable of absorbing or emitting infrared radiation, but several of the triatomic gases, such as water vapor, carbon dioxide, and ozone are infrared-active and play important roles in the propagation of infrared radiation in the atmosphere.

The earth radiates with maximum intensity in the infrared portion of the spectrum (near 10 microns).

**Injection.** – 1. The introduction of fuel, fuel and air, fuel and oxidizer, water, or other substance into an engine induction system or combustion chamber. 2. The process of putting an artificial satellite into orbit. 3. The time following launching when non-gravitational forces (thrust, life, and drag) become negligible in their effect on the trajectory of a space vehicle.

More than one injection is possible in a single flight if engines are stopped and restarted.

**Intensity.** – 1. In general, the degree or amount, usually expressed by the elemental time rate or spatial distribution, of some condition or physical quantity, such as electric field, sound, magnetism, etc. 2. With respect to electromagnetic radiation, a measure of the radiant flux per unit solid angle emanating from some source. Frequently, it is desirable to specify this as radiant intensity in order to clearly distinguish it from luminous intensity.

**Interface.** – The junction points or the points within or between systems or subsystems where matching or accommodation must be properly achieved in order to make their operation compatible with the successful operation of all other functional entities in the space vehicle and its ground support.

**International Geophysical Year (abbr IGY).** – By international agreement, a period during which greatly increased observation of world-wide geophysical phenomena is undertaken through the cooperative effort of participating nations. July, 1957-December, 1958 was the first such 'year'; however, precedent was set by the International Polar Years of 1882 and 1921.

**International Year of the Quiet Sun (abbr IQSY).** – The international program for maximum observation and research in connection with expected period of low solar activity between April, 1964 and December, 1965.

**Ion.** – An atom or molecularly bound group of atoms having an electric charge. Sometimes also a free electron or other charged subatomic particle.

**Ionosphere.** – The atmospheric shell characterized by a high ion density. Its base is at about 50 km, and it extends to an indefinite height.

The ionosphere is classically divided into regions with each region except D Region, the lowest in altitude, supposedly characterized by a more or less regular maximum of electron density.

The D Region exists only in the daytime when it is characterized by increasing electron and ion density, moving upward from about 50 km and merging with the bottom of the E Region.

The lowest clearly defined layer is the E Region, occurring between 90 and 160 km. The $F_1$ and $F_2$ Regions occur in general above 160 km, the $F_1$ Region being always present and having the higher electron density. The existence of a G Region has been suggested, but is questionable.

Sudden increases in ionization of particular regions are, referred to as 'sporadic', as in 'sporadic E' or 'sporadic D'.

The above assumption that the ionosphere is stratified in the vertical into discrete layers is currently under serious question. Some evidence supports a belief that ion clouds are the basic elements of the ionosphere. Other investigations appear to reveal the ionosphere as a generally ionized region characterized by more or less random fluctuations of electron density.

**Isotropic.** – In general, pertaining to a state in which a quantity or spatial derivatives thereof are independent of direction.

**IQSY.** – See **International Year of the Quiet Sun.**

**Jerk.** – A vector that specifies the time rate of change of an acceleration; the third derivative of displacement with respect to time.

**Joule's Constant.** – The ratio between heat and work units from experiments based on the first law of thermodynamics: 4.186 x $10^7$ ergs/cal. Also called 'mechanical equivalent of heat'.

**Kelvin Temperature Scale (abbr K).** – An absolute temperature scale independent of the thermometric properties of the working substance. On this scale, the difference between two temperatures $T_1$ and $T_2$ is proportional to the heat converted into mechanical work by a Carnot engine operating between the isotherms and adiabats through $T_1$ and $T_2$. Also called 'absolute temperature scale', 'thermodynamic temperature scale'.

For convenience the Kelvin degree is identical to the Celsius degree. The ice point in the Kelvin scale is 273.16°K. See **Absolute Zero.**

**Kepler's Laws.** – The three empirical laws describing the motions of planets in their orbits, discovered by Johannes Kepler (1571-1630). These are: (1) The orbits of the planets are ellipses, with the sun at a common focus. (2) As a planet moves in its orbit, the line joining the planet and sun sweeps over equal areas in equal intervals of time. Also called 'law of equal areas'. (3) The squares of the periods of revolution of any two planets are proportional to the cubes of their mean distances from the sun.

**Kirchhoff's Law.** – The radiation law which states that at a given temperature the ratio of the emissivity to the absorptivity for a given wavelength is the same for all bodies and is equal to the emissivity of an ideal black body at that temperature and wavelength.

Loosely put, this important law asserts that good absorbers of a given wavelength are also good emitters of that wavelength. It is essential to note that Kirchhoff's law relates absorption and emission at the same wavelength and at the same temperature. Also called 'Kirchhoff's radiation law'.

**Laser.** – (From light amplification by stimulated emission of radiation). A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal.

**Launch Pad.** – The load-bearing base or platform from which a rocket vehicle is launched. Usually called 'pad'.

**Launch Vehicle.** – Any device which propels and guides a spacecraft into orbit about the earth or into a trajectory to another celestial body. Often called 'booster'.

**Launch Window.** – An interval of time during which a rocket can be launched to accomplish a particular purpose as 'lift-off occurred 5 minutes after the beginning of the 82-minute launch window'.

**Libration.** – A real or apparent oscillatory motion, particularly the apparent oscillation of the moon.

*Because of libration, more than half of the moon's surface is revealed to an observer on the earth, even though the same side of the moon is always toward the earth because the moon's periods of rotation and revolution are the same.*

**Lift-off.** – The action of a rocket vehicle as it separates from its launch pad in a vertical ascent.

*A lift-off is applicable only to vertical ascent; a take-off is applicable to ascent at any angle. A lift-off is action performed by a rocket; a launch is action performed upon a rocket or upon a satellite or spaceship carried by a rocket.*

**Liquid-propellant Rocket Engine.** – A rocket engine fueled with a propellant or propellants in liquid form. Also called 'liquid-propellant rocket'.

*Rocket engines of this kind vary somewhat in complexity, but they consist essentially of one or more combustion chambers together with the necessary pipes, valves, pumps, injectors, etc.*

**Local Vertical.** – At a particular point, the direction in which the force of gravity acts.

**Longitudinal Axis.** – The fore-and-aft line through the center of gravity of a craft.

**Longitudinal Vibration.** – Vibration in which the direction of motion of the particles is the same as the direction of advance of the vibratory motion.

This is in contrast with transverse vibration, in which the direction of motion is perpendicular to that of advance.

**Lox.** – 1. Liquid oxygen. Used attributively as in 'lox tank', 'lox unit'. Also called 'loxygen'. 2. To load the fuel tanks of a rocket vehicle with liquid oxygen. Hence, 'loxing'.

**Lunar Atmospheric Tide.** – An atmospheric tide due to the gravitational attraction of the moon. The only detectable components are the 12-lunar-hour or semidiurnal, as in the oceanic tides, and two others of very nearly the same period. The amplitude of this atmospheric tide is so small that it is detected only by careful statistical analysis of a long record, being about 0.06 mb in the tropics and 0.02 mb in the middle latitudes.

**Mach Number.** – (After Ernst Mach (1838-1916), Austrian scientist.) A number expressing the ratio of the speed of a body or of a point on a body with respect to the surrounding air or other fluid, or the speed of a flow, to the speed of sound in the medium; the speed represented by this number.

*If the Mach number is less than one, the flow is called 'subsonic' and local disturbances can propagate ahead of the flow. If the Mach number is greater than one, the flow is called 'supersonic' and disturbance cannot propagate ahead of the flow, with the result that shock waves form.*

**Magnetic Storm.** – A worldwide disturbance of the earth's magnetic field.

*Magnetic storms are frequently characterized by a sudden onset, in which the magnetic field undergoes marked changes in the course of an hour or less, followed by a very gradual return to normality, which may take several days. Magnetic storms are caused by solar disturbances, though the exact nature of the link between the solar and terrestrial disturbances is not understood. Sometimes a magnetic storm can be linked to a particular solar disturbance. In these cases, the time between solar flare and onset of the magnetic storm is about one or two days, suggesting that the disturbance is carried to the earth by a cloud of particles thrown out by the sun.*

**Magnetohydrodynamics.** – The study of the interaction that exists between a magnetic field and an electrically conducting fluid. Also called 'magnetoplasmadynamics', 'magnetogas-dynamics', 'hydromagnetics', 'MHD'.

**Magnetometer.** – An instrument used in the study of geomagnetism for measuring any magnetic element.

**Magnetosphere.** – The region above the ionosphere in which the earth's magnetic field dominates over extraterrestrial magnetic fields.

**Magnitude.** – Relative brightness of a celestial body. The smaller the magnitude number, the brighter the body.

*Decrease of light by a factor of 100 increases the steller magnitude by 5.00; hence the brightest objects have negative magnitudes. (Sun: -26.8; mean full moon; -12.5; Venus at brightest: -4.3; Jupiter at opposition: -2.3; Sirius; -1.6; Vega: +0.2; Polaris: +2.1). The faintest stars visible to the naked eye on a clear dark night are of about the sixth magnitude.*

**Main Stage.** – 1. In a multistage rocket, the stage that develops the greatest amount of thrust, with or without booster engines. 2. In a single-stage rocket vehicle powered by one or more engines, the period when full thrust (at or above 90 percent) is attained. 3. A sustainer engine, considered as a stage after booster engines have fallen away, as in 'the main stage of the Atlas'.

**Maser.** – An amplifier utilizing the principle of microwave amplification by stimulated emission of radiation. Emission of energy stored in a molecular or atomic system by a microwave power supply is stimulated by the input signal.

**Mass.** – The measure of the amount of matter in a body, thus its inertia.

*The weight of a body is the force with which it is attracted by the earth.*

**Mass Ratio.** – The ratio of the mass of the propellant charge of a rocket to the total mass of the rocket charged with the propellant.

**Mate.** – To fit together two major components of a system.

**Mean Free Path.** – Of any particle, the average distance that a particle travels between successive collisions with the other particles of an ensemble.

**Mega.** – A prefix meaning multiplied by one million as in 'megacycles'.

**Memory.** – The component of a computer, control system, guidance system, instrumented satellite, or the like designed to provide ready access to data or instructions previously recorded so as to make them bear upon an immediate problem, such as the guidance of a physical object, or the analysis and reduction of data.

**Mesosphere.** – 1. The atmospheric shell between about 20 km and about 70 or 80 km, extending from the top of the stratosphere to the upper temperature minimum (the mesopause). It is characterized by a broad temperature maximum (the mesopeak) at about 50 km, except possibly over the winter polar regions. 2. The atmospheric shell between the top of the ionosphere (the top of this region has never been clearly defined) and the bottom of the exosphere. (This definition has not gained general acceptance.)

**Meteor.** – In particular, the light phenomenon which results from the entry into the earth's atmosphere of a solid particle from space: more generally, any physical object or phenomenon associated with such an event.

**Meteorite.** – A meteoroid which has reached the surface of the earth without being completely vaporized.

**Meteoroid.** – A solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom or molecule.

**Meteorological Rocket.** – A rocket designed primarily for routine upper-air observation (as opposed to research) in the lower 250,000 feet of the atmosphere, especially that portion inaccessible to balloons, i.e., above 100,000 feet. Also called 'rocketsonde'.

**Micro.** – 1. A prefix meaning divided by one million. 2. A prefix meaning very small as in 'micrometeorite'.

**Microbar (abbr μb).** – The unit of pressure in the c.g.s. system and equal to one dyne per square centimeter.

**Micrometeorite.** – A very small meteorite or meteoritic particle with a diameter in general less than a millimeter.

**Micron.** – One millionth of a meter, abbreviated $\mu$.

**Microwave Region.** – Commonly, that region of the radio spectrum between approximately 1,000 Mc and 300,000 Mc.

Corresponding wavelengths are 30 cm to 1 mm.

The limits of the microwave region are not clearly defined but in general it is considered to be the region in which radar operates.

**Millibar.** – A unit of pressure equal to 1,000 dynes per square centimeter, or 1/1,000 of a bar.

The millibar is used as a unit of measure of atmospheric pressure, a standard atmosphere being equal to 1,013.25 millibars or 29.92 inches of mercury.

**Mini.** – A contraction of 'miniature' used in combination, as in 'minicomponent', 'miniradio', 'minitransistor'.

**Miniaturize.** – To construct a functioning miniature of a part or instrument. Said of telemetering instruments or parts used in an earth satellite or rocket vehicle, where room is at a premium. Hence, 'miniaturized', 'miniaturization'.

**Minimum Ionizing Speed.** – The speed with which a free electron must move through a given gas to be able to ionize gas atoms or molecules by collision. In air at standard conditions, this speed is about $10^7$ cm/sec.

**Minitrack.** – A satellite tracking system consisting of a field of separate antennas and associated receiving equipment interconnected so as to form interferometers which track a transmitting beacon in the satellite itself.

**Missile.** – Any object thrown, dropped, fired, launched, or otherwise projected with the purpose of striking a target. Short for 'ballistic missile', 'guided missile'.

*Missile is loosely used as a synonym for 'rocket' or 'spacecraft' by some careless writers.*

**Mock-Up.** – A full-sized replica or dummy of something, such as a spacecraft, often made of some substitute material, such as wood, and sometimes incorporating functioning pieces of equipment, such as engines.

**Mode of Propagation.** – In transmission, a form of propagation of guided waves that is characterized by a particular field pattern in a plane transversed to the direction of propagation, which field pattern is independent of position along the axis of the wave-guide.

In the case of uniconductor waveguides the field pattern of a particular mode of propagation is also independent of frequency.

**Mode of Vibration.** – In a system undergoing vibration, a characteristic pattern assumed by the system, in which the motion of every particle is simple harmonic with the same frequency.

Two or more modes of vibration may exist concurrently in a multiple-degree-of-freedom system.

**Modulation.** – Specifically, variation of some characteristic of a radio wave, called the 'carrier wave', in accordance with instantaneous values of another wave, called the 'modulating wave'.

*Variation of amplitude is amplitude modulation, variation of frequency is frequency modulation, and variation of phase is phase modulation. The formation of very short bursts of a carrier wave, separated by relatively long periods during which no carrier wave is transmitted, is pulse modulation.*

**Module.** – 1. A self-contained unit of a launch vehicle or spacecraft which serves as a building block for the overall structure. The module is usually designated by its primary function as 'command module', 'lunar landing module', etc. 2. A one-package assembly of functionally associated electronic parts; usually a plug-in unit.

**Moment (abbr M).** – A tendency to cause rotation about a point or axis, as of a control surface about its hinge or of an airplane about its center of gravity; the measure of this tendency, equal to the product of the force and the perpendicular distance between the point of axis of rotation and the line of action of the force.

**Moment of Inertia (abbr I).** – Of a body about an axis, the $\Sigma\, mr^2$, where m is the mass of a particle of the body and r its distance from the axis.

**Momentum.** – Quantity of motion.

Linear momentum is the quantity obtained by multiplying the mass of a body by its linear speed. Angular momentum is the quantity obtained by multiplying the moment of inertia of a body by its angular speed.

The momentum of a system of particles is given by the sum of the moments of the individual particles which make up the system, or by the product of the total mass of the system and the velocity of the center of gravity of the system.

The momentum of a continuous medium is given by the integral of the velocity over the mass of the medium, or by the product of the total mass of the medium and the velocity of the center of gravity of the medium.

**Monopropellant.** – A rocket propellant consisting of a single substance, especially a liquid, capable of producing a heated jet without the addition of a second substance.

**M-Region.** – Name given to a region of activity on the sun when the nature of that activity cannot be determined.

The M-region used in accounting for recurrent magnetic storms with a period the same as the period of solar rotation relative to the earth, 27.3 days. See **Magnetic Storm.**

**Multiplexer.** – A mechanical or electrical device for sharing of a circuit by two or more coincident signals.

**Multiplexing.** – The simultaneous transmission of two or more signals within a single channel.

*The three basic methods of multiplexing involve the separation of signals by time division, frequency division, and phase division.*

**Multipropellant.** – A rocket propellant consisting of two or more substances fed separately to the combustion chamber.

**Multistage Rocket.** – A vehicle having two or more rocket units, each unit firing after the one in back of it has exhausted its propellant. Normally, each unit, or stage, is jettisoned after completing its firing. Also called a 'multiple-stage rocket' or, infrequently, a 'step rocket'.

**Musa Antenna.** – A 'multiple-unit steerable antenna' consisting of a number of stationary antennas, the composite major lobe of which is electrically steerable.

**NACA (abbr).** – National Advisory Committee for Aeronautics.

**Nano.** – A prefix meaning divided by one billion, as in 'nanosecond', one billionth of a second.

**Nanosecond (abbr nsec).** – $10^{-9}$ second. Also called 'millimicrosecond'.

**NASA (abbr).** – National Aeronautics and Space Administration.

**NASC (abbr).** – National Aeronautics and Space Council.

**Natural Frequency.** – The frequency of free vibration of a body, expressed in cycles per unit time. For a multiple-degree-of-freedom system, the natural frequencies or frequencies of the normal modes of vibration. Mathematically expressed as the square root of stiffness divided by mass, $\sqrt{\frac{k}{m}}$. See **Free Vibration.**

**Nautical Mile.** – A unit of distance used principally in navigation. For practical navigation it is usually considered the length of one minute of any great circle of the earth, the meridian being the great circle most commonly used. Also called 'sea mile'. By international agreement of July 1, 1959, US Great Britain and nearly all maritime nations established the International Nautical Mile, equal to exactly 1852 meters. Using the yard-meter conversion factor effective July 1, 1959, the International Nautical Mile is equivalent to 6,076.11549 international feet.

**NASA's Designated Representative.** – A representative of the NASA installation stationed at the supplier's plant or a representative of the inspection agency to whom quality assurance functions have been delegated.

**NASA Installation.** – A major organizational unit of the NASA; includes Headquarters and field installations. Field installations are assigned specific missions in the NASA space program.

**Neutron.** – A subatomic particle with no electric charge, and with a mass slightly more than the mass of the proton.

Protons and neutrons comprise atomic nuclei; and they are both classed as nucleons.

**Neutrosphere.** – The atmospheric shell from the earth's surface upward in which the atmospheric constituents are for the most part un-ionized, i.e., electrically neutral.

The region of transition between the neutrosphere and the ionosphere is somewhere between 70 and 90 km, depending on latitude and season.

**Newton's Laws of Motion.** – A set of three fundamental postulates forming the basis of the mechanics of rigid bodies, formulated by Newton in 1687.

*The first law is concerned with the principle of inertia and states that if a body in motion is not acted upon by an external force, its momentum remains constant (law of conservation of momentum). The second law asserts that the rate of change of momentum of a body is proportional to the force acting upon the body and is in the direction of the applied force. A familiar statement of this is the equation*

$$F = ma,$$

*where F is vector sum of the applied forces, m the mass, and a the vector acceleration of the body. The third law is the principle of action and reaction, stating that for every force acting upon a body there exists a corresponding force of the same magnitude exerted by the body in the opposite direction.*

**Noctilucent Clouds.** – Rarely observed clouds of unknown composition which occur at great height. Photometric measurements have located them between 75 and 90 km. They resemble thin cirrus, but usually with a bluish or silverish color, although sometimes orange to red, standing out against a dark night sky. Sometimes called 'luminous clouds.'

**Node.** – 1. One of the two points of intersection of the orbit of a planet, planetoid, or comet with the ecliptic, or of the orbit of a satellite with the plane of the orbit of its primary. Also called 'nodal point'.

That point at which the body crosses to the north side of the reference plane is called the ascending node; the other, the descending node. The line connecting the nodes is called line of nodes.

2. A point, line, or surface in a standing wave where some characteristic of the wave has essentially zero amplitude.

The appropriate modifier should be used before the word 'node' to signify the type that is intended; e.g., displacement node, velocity node, pressure node.

3. A terminal of any branch of a network or a terminal common to two or more branches of a network. Also called 'junction point', 'branch point', or 'vertex'.

**Noise.** – 1. Any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. When caused by natural electrical discharges in the atmosphere noise may be called 'static'.

2. An erratic, intermittent, or statistically random oscillation.

If uncertainty exists as to the nature of the noise, a phrase such as 'acoustic noise' or 'electric noise' should be used.

Since the above definitions are not mutually exclusive, it is usually necessary to depend upon context for the distinction.

**Normal Mode of Vibration.** – A mode of free vibration of an undamped system. In general, any composite motion of a vibrating system is analyzable into a summation of its normal modes, also called natural mode, 'characteristic mode', and 'eigen mode'.

**Nosecone.** – The cone-shaped leading end of a rocket vehicle, consisting (a) of a chamber or chambers in which a satellite, instruments, animals, plants, or auxiliary equipment may be carried, and (b) of an outer surface built to withstand high temperatures generated by aerodynamic heating.

*In a satellite vehicle, the nosecone may become the satellite itself after separating from the final stage of the rocket or it may be used to shield the satellite until orbital speed is accomplished, then separating from the satellite. See* **Shroud.**

**Nozzle.** – Specifically, the part of a rocket thrust chamber assembly in which the gases produced in the chamber are accelerated to high velocities.

**Nuclear Fuel.** – Fissionable material of reasonably long life, used or usable in producing energy in a nuclear reactor.

**Nuclear Radiation.** – The emission of neutrons and other particles from an atomic nucleus as the result of nuclear fission or nuclear fusion.

**Nuclear Reactor.** – An apparatus in which nuclear fission may be sustained in a self-supporting chain reaction. Commonly called 'reactor'.

**Nucleus.** – The positively charged core of an atom with which is associated practically the whole mass of the atom but only a minute part of its volume.

*A nucleus is composed of one or more protons and an approximately equal number of neutrons.*

**Octave.** – The interval between any two frequencies having the ratio of 1:2.

The interval in octaves between any two frequencies is the logarithm to the base 2 (or 3.322 times the logarithm to the base 10) of the frequency ratio.

**Orbit.** – 1. The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves. 2. To go around the earth or other body in an orbit.

**Orbital Elements.** – A set of 7 parameters defining the orbit of a satellite.

**Orbital Period.** – The interval between successive passages of a satellite.

**Orbital Velocity.** – 1. The average velocity at which an earth satellite or other orbiting body travels around its primary. 2. The velocity of such a body at any given point in its orbit, as in 'its orbital velocity at the apogee is less than at the perigee'.

**Order of Magnitude.** – A factor of 10.

*Two quantities of the same kind which differ by less than a factor of 10 are said to be of the same order of magnitude. 'Order of magnitude' is used loosely by many writers to mean a pronounced difference in quantity on the basis of the context.*

**Orthogonal.** – At right angles.

**Otolith.** – A small calcareous concretion located in the inner ear which plays a part in the mechanism of orientation.

**Outgassing.** – The evolution of gas from a solid in a vacuum.

**Oxidizer.** – Specifically, a substance (not necessarily containing oxygen) that supports the combustion of a fuel or propellant.

**Ozonosphere.** – The general stratum of the upper atmosphere in which there is an appreciable ozone concentration and in which ozone plays an important part in the radiative balance of the atmosphere. This region lies roughly between 10 and 50 km, with maximum ozone concentration at about 20 to 25 km. Also called 'ozone layer.'

**Pad** = **Launch Pad.**

**Paraglider.** – A flexible-winged, kite-like vehicle designed for use in a recovery system for launch vehicles or as a reentry vehicle.

**Parameter.** – 1. In general, any quantity of a problem that is not an independent variable. More specifically, the term is often used to distinguish, from dependent variables, quantities which may be more or less arbitrarily assigned values for purposes of the problem at hand. 2. In statistical terminology, any numerical constant derived from a population or a probability distribution. Specifically, it is an arbitrary constant in the mathematical expression of a probability distribution.

**Part.** – An element of a component, assembly or subassembly which is not normally subject to further subdivision or disassembly for maintenance purposes. Examples are: resistors, transformers, electron tubes, relays, etc.

**Passive.** – Reflecting a signal without transmission, as 'Echo is a passive satellite'. Contrasted with 'active'.

**Payload.** – 1. Originally, the revenue-producing portion of an aircraft's load, e.g., passengers, cargo, mail, etc. 2. By extension, that which an aircraft, rocket, or the like carries over and above what is necessary for the operation of the vehicle during its flight.

**Peri.** – A prefix meaning near, as in 'perigee'.

**Perigee.** – That orbital point nearest the earth when the earth is the center of attraction.

*That orbital point farthest from the earth is called 'apogee'. Perigee and apogee are used by many* *writers in referring to orbits of satellites, especially artificial satellites, around any planet or satellite, thus avoiding coinage of new terms for each planet and moon.*

**Pencil-Beam Antenna.** – A unidirectional antenna, so designed that cross sections of the major lobe by planes perpendicular to the direction of maximum radiation are approximately circular.

**Perihelion.** – That orbital point nearest the sun when the sun is the center of attraction. That orbital point farthest from the sun is called 'aphelion'. The term 'perihelion' should not be confused with 'parhelion', a form of halo.

**Period.** – The interval needed to complete a cycle. Often used in reference to time of complete orbit.

**Perturbation.** – Specifically, a disturbance in the regular motion of a celestial body, the result of a force additional to those which cause the regular motion.

**Photon.** – According to the quantum theory of radiation, the elementary quantity, or 'quantum' of radiant energy. It is regarded as a discrete quantity having a mass equal to $hv/c^2$, where h is Planck's constant, v the frequency of radiation, and c the speed of light in a vacuum.

**Photon Engine.** – A projected type of reaction engine in which thrust would be obtained from a stream of electromagnetic radiation.

*Although the thrust of this engine would be minute, it may be possible to apply it for extended periods of time. Theoretically, in space, where no resistance is offered by air particles, very high speeds may be built up.*

**Photosphere.** – The intensely bright portion of the sun visible to the unaided eye. The photosphere is that portion of the sun's atmosphere which emits the continuous radiation upon which the Fraunhofer lines are superimposed. In one sun model, the photosphere, is thought to be below the reversing layer in which Fraunhofer absorption takes place. In another model, all strata are considered equally effective in producing continuous emissions and line absorption.

**Pickoff.** – A sensing device used in combination with a gyroscope in an automatic pilot or other automatic or robot apparatus, that responds to angular movement to create a signal or to effect some type of control.

**Pickup.** – 1. A device that converts a sound, scene, or other form of intelligence into corresponding electric signals (e.g., a microphone, a television camera, or a phonograph pickup). 2. The minimum current, voltage, power, or other value at which a relay will complete its intended function. 3. Interference from a nearby circuit or system.

**Planck's Constant (abbr h).** – A constant, usually designated h, of dimensions mass x length$^2$ x time$^{-1}$ equal to $6.6252 \times 10^{-27}$ erg sec. It scales the energy of electromagnetic radiation of frequency v such that the radiation appears only in quanta nhv, n being an integer.

**Planck's Law.** – An expression for the variation of monochromatic emittance (emissive power) as a function of wavelength of black-body radiation at a given temperature; it is the most fundamental of the radiation laws.

**Planet.** – A celestial body of the solar system, revolving around the sun in a nearly circular orbit, or a similar body revolving around a star.

*The larger of such bodies are sometimes called 'principal planets' to distinguish them from asteroids, planetoids, or minor planets, which are comparatively very small.*

*An inferior planet has an orbit smaller than that of the earth; a superior planet has an orbit larger than that of the earth. The four planets nearest the sun are called 'inner planets'; the others, 'outer planets'. The four largest planets are called 'major planets'. The word 'planet' is of Greek origin, meaning, literally, wanderer, applied because the planets appear to move relative to the stars.*

**Plasma.** – An electrically conductive gas comprised of neutral particles, ionized particles and free electrons but which, taken as a whole, is electrically neutral.

A plasma is further characterized by relatively large intermolecular distances, large amounts of energy stored in the internal energy levels of the particles and by the presence of a plasma sheath at all boundaries of the plasma.

Plasmas are sometimes referred to as a fourth state of matter.

**Plasma Engine.** – A reaction engine using magnetically accelerated plasma as propellant.

*A plasma engine is a type of electrical engine.*

**Plasma Jet.** – A magnetohydrodynamic rocket engine in which the ejection of plasma generates thrust.

**Plasma Sheath.** – 1. The boundary layer of charged particles between a plasma and its surrounding walls, electrodes, or other plasmas.

The sheath is generated by the interaction of the plasma with the boundary material. Current flow may be in only one direction across the sheath (single sheath), in both directions across the sheath (double sheath), or when the plasma is immersed in a magnetic field, may flow along the sheath surface at right angles to the magnetic field (magnetic current sheath).

2. An envelope of ionized gas that surrounds a body moving through an atmosphere at hypersonic velocities.

The plasma sheath affects transmission, reception, and diffraction of radio waves; thus is important in operational problems of spacecraft, especially during reentry.

**Pod.** – An enclosure, housing, or detachable container of some kind, as: (a) an engine pod, (b) an ejection capsule.

**Polarization.** – 1. The state of electromagnetic radiation when transverse vibrations take place in some regular manner, e.g., all in one plane, in a circle, in an ellipse, or in some other definite curve.

Radiation may become polarized because of the nature of its emitting source, as is the case with many types of radar antennas, or because of some processes to which it is subjected after leaving its source, as that which results from the scattering of solar radiation as it passes through the earth's atmosphere.

**Posigrade Rocket.** – An auxiliary rocket which fires in the direction in which the vehicle is pointed, used for example in separating two stages of a vehicle.

**Pound (abbr lb).** – 1. A unit of weight equal in the United States to 0.45359237 kilograms. 2. Unit of force, 1 pound defined as the force required to impart an acceleration of 1 ft/sec$^2$ to a mass of 1 slug. 3. Specifically, a unit of measurement for the thrust or force of a reaction engine representing the weight the engine can move, as an engine with 100,000 pounds of thrust.

**Power Spectral Density (abbr PSD).** – Limiting mean square value (e.g., of acceleration, velocity, displacement, stress or other random variable) per unit bandwidth, i.e., the limit of the mean-square value in a given rectangular bandwidth, as the bandwidth approaches zero.

*In the random vibration phase of spacecraft environmental testing, PSD is expressed as* $g^2$*/cps and is a measure of the energy within a given frequency band.*

**Precession.** – Change in the direction of the axis of rotation of a spinning body, as a gyroscope, when acted upon by a torque.

The direction of motion of the axis is such that it causes the direction of spin of the gyroscope to tend to coincide with that of the impressed torque. The horizontal component of precession is called 'drift', and the vertical component is called 'topple'.

**Pressure (abbr p).** – Force per unit area. As measured in a vacuum system, the quantity measured at a specified time by a so-called vacuum gage, whose sensing element is located in a cavity (gage tube) with an opening oriented in a specified direction at a specified point within the system, assuming a specified calibration factor.

The sensitivity of the sensing element is in general not the same for all molecular species, but the gage reading is frequently reported using the calibration factor for air regardless of the composition of the gas. The opening to the gage tube is often carelessly oriented with respect to mass-flow vectors in the gas (which is seldom at rest), and errors due to variations in wall temperatures of tube and system are frequently neglected. The actual total pressure in a high-vacuum system cannot usually be measured by a single gage, but in vacuum technology the term 'total pressure' is sometimes used to refer to the reading of a single untrapped gage which responds to condensable vapors as well as permanent gases.

**Pressurized.** – Containing air, or other gas, at a pressure that is higher than the pressure outside the container.

**Prestage.** – A step in the action of igniting a large liquid rocket taken prior to the ignition of the full flow, and consisting of igniting a partial flow of propellants into the thrust chamber.

**Primary Body.** – The spatial body about which a satellite or other body orbits, or from which it is escaping, or towards which it is falling.

*The primary body of the moon is the earth; the primary body of the earth is the sun.*

**Primary Cosmic Rays.** – High energy particles originating outside the earth's atmosphere.

Primary cosmic rays appear to come from all directions in space. Their energy appears to range from $10^9$ to more than $10^{17}$ electron volts.

**Probable Error (abbr pe).** – In statistics, that value $e_p$ for which there exists an even probability (0.5) that the actual error exceeds $e_p$. The probable error $e_p$ is 0.6745

times the standard deviation $\sigma$.
The probable error is not 'probable' in the normal sense of the word.

**Probability.** – The chance that a prescribed event will occur, represented as a number greater than zero but less than one. The probability of an impossible event is zero, and that of an inevitable event is one.

**Probe.** – Any device inserted in an environment for the purpose of obtaining information about the environment. Specifically, an instrumented vehicle moving through the upper atmosphere or space or landing upon another celestial body in order to obtain information about the specific environment.
Almost any instrumented spacecraft can be considered a probe. However, earth satellites are not usually referred to as 'probes'. Also, almost any instrumented rocket can be considered a probe. In practice, rockets which attain an altitude of less than one earth radius (4000 miles) are called 'sounding rockets', those which attain an altitude of more than one earth radius are called 'probes' or 'space probes'. Spacecraft which enter into orbit around the sun are called 'deep-space probes'. Spacecraft designed to pass near or land on another celestial body are often designated 'lunar probe', 'Martian probe', 'Venus probe', etc.

**Prominence.** – A filament-like protuberance from the chromosphere of the sun.
Prominences can be observed (optically) whenever the sun's disk is masked, as during an eclipse or using a coronagraph; and can be observed instrumentally by filtering in certain wavelengths, as with a spectroheliograph. A typical prominence is 6,000 to 12,000 km thick, 60,000 km high, and 200,000 km long.

**Propellant.** – Short for 'rocket propellant'.

**Proton.** – A positively-charged subatomic particle having a mass slightly less than that of a neutron but about 1847 times greater than that of an electron. Essentially, the proton is the nucleus of the hydrogen isotope ${}_1H^1$ (ordinary hydrogen stripped of its orbital electron). Its electric charge ($+4.8025 \times 10^{-10}$ esu) is numerically equal, but opposite in sign, to that of the electron.
Protons and neutrons comprise atomic nuclei; they are both classed as 'nucleons'.

**Protonosphere.** – The outer layer of the atmosphere where the main constituent is the proton.

**Prototype.** – Spacecraft or element thereof which is undergoing or has passed environmental and other tests (Design Qualification Environmental Tests) which qualify design for fabrication of flight units or elements thereof. Compare flight unit.

**Proving Stand.** – A test stand for reaction engines, especially rocket engines.

**Purge.** – To rid a line or tank of residual fluid, especially of fuel or oxygen in the tanks or lines of a rocket after a test firing or simulated test firing.

**q = Dynamic Pressure.**

**Quality.** – The inherent or acquired characteristics of an item which when measured against a standard or model establish the degree of conformity of the item to the standard or model. (The quality organization is responsible to top management on the same basis as functions like engineering, manufacturing or procurement. The purpose of the quality organization is the prevention of defects in the item being prepared.)

**Quality Assurance.** – A management monitoring and auditing function which confirms through inspection and verification that effective quality control has been and is being conducted, thus providing confidence that the end item will perform satisfactorily in actual operations.

**Quality Control.** – A management function by which the conformance of material to established standards and specifications is achieved, the quality and reliability of materials are measured, and in the event of defects, corrective action is effected. (This includes the control of raw materials, incoming articles, manufacturing processes and operations and the employee training and certification program.)

**Quality Engineering.** – A management function responsible for the development of Quality Control and Quality Assurance Procedures to achieve the goals of a reliability program. (Since the Control and Assurance Provisions will depend on the manufacturing process which in turn is a function of the Engineering Design, these three quality activities participate in Engineering Design Reviews.)

**Quantization.** – The process of converting from continuous values of information to a finite number of discrete values.

**Quiet Sun.** – Descriptive of sun's condition when number of sunspots is low and flare activity is at a minimum. See **Year of the Quiet Sun.**

**Radiation.** – Short for 'electromagnetic radiation', 'nuclear radiation'.

**Radiation Pressure (abbr Pr).** – Pressure exerted upon any material body when electromagnetic radiation is incident upon body.

This pressure is manifested whenever the electromagnetic momentum in a radiation field is changed, and is exactly twice as great when the radiation is reflected at normal incidence as it is when the radiation is entirely absorbed at normal incidence. The magnitude of any radiation pressure effect is directly proportional to the intensity of the radiation, and is very small by most standards.

On a perfectly reflecting surface $Pr = v/3$ where $v$ = radiation density the amount of radiative energy per unit volume in the space above the surface. Radiation pressure has a perceptible effect on the orbit of earth satellites, especially those with a large reflecting surface such as Echo.

**Radiation Shield.** – 1. A device used on certain types of instruments to prevent unwanted radiation from biasing the measurement of a quantity. 2. A device used to protect bodies from the harmful effects of nuclear radiation, cosmic radiation, or the like.

**Radiator.** – 1. Any source of radiant energy, especially electromagnetic radiation. 2. A device that dissipates heat from something, as from water or oil, not necessarily by radiation only.

*Generally, the application of the terms 'radiator' (in sense 2) or 'heat exchanger' to a particular apparatus depends upon the point of view: If the emphasis is upon merely getting rid of heat, 'radiator' is most often used, or sometimes 'cooler'; if the emphasis is upon transferring heat, 'heat exchanger' is used–but these* *distinctions do not always hold true.*

**Radiosonde.** – A balloon-borne instrument for the simultaneous measurement and transmission of meteorological data.

**Random Vibration.** – Vibration whose instantaneous magnitude cannot be predicted for any given time. The instantaneous magnitudes of a random vibration are specified only by probability distribution functions, giving the probable fraction of the total time that the magnitude (or some sequence of magnitudes) lies within a specified range. Random vibration contains no periodic or quasi-periodic constituents. See **Gaussian Distribution.** Compare sinusoidal vibration and combustion resonance.

*Random vibration is applied to a spacecraft in environmental testing to simulate one aspect of vibration in the launch phase of space missions.*

**Reaction Control System.** – A system of controlling the attitude of a craft when outside the atmosphere by using jets of gas in lieu of aerodynamic control surfaces.

**Reaction Engine.** – An engine that develops thrust by its reaction to ejection of a substance from it; specifically, such an engine that ejects a jet or stream of gases created by the burning of fuel within the engine.

*A reaction engine operates in accordance with Newton's third law of motion, i.e., to every action (force) there is an equal and opposite reaction. Both rocket engines and jet engines are reaction engines.*

**Readout.** – 1. The action of a radio transmitter transmitting data either instantaneously with the acquisition of the data or by play of a magnetic tape upon which the data have been recorded. 2. In computer operations to extract information from storage.

**Readout Station.** – A recording or receiving radio station at which data are received from a transmitter in a probe, satellite, or other spacecraft.

**Real Time.** – Time in which reporting on events or recording of events is simultaneous with the events.

*For example, the real time of a satellite is that time in which it simultaneously reports its environment as it encounters it; the real time of a computer is that time during which it is accepting data.*

**Recombination.** – The process by which a positive and a negative ion join to form a neutral molecule or other neutral particle.

**Recovery.** – The procedure or action that obtains when the whole of a satellite, or a satellite instrumentation package, or other part of a rocket vehicle is recovered after a launch; the result of this procedure.

**Recycle.** – In a countdown: To stop the count and to return to an earlier point in the countdown, as in 'we have recycled, now at T minus 80 and counting'. Compare hold. In testing: to repeat a group or series of tests.

**Reentry.** – The event occurring when a spacecraft or other object comes back into the sensible atmosphere after being rocketed to altitudes above the sensible atmosphere; the action involved in this event.

**Reentry Vehicle.** – A space vehicle designed to return with its payload to earth through the sensible atmosphere.

**Reentry Window.** – The area at the limits of the earth's atmosphere through which a spacecraft in a given trajectory can pass to accomplish a successful reentry.

**Regenerative Cooling.** – The cooling of a part of an engine by the propellant being delivered to the combustion chamber; specifically, the cooling of a rocket-engine combustion chamber or nozzle by circulating the fuel or oxidizer, or both, around the part to be cooled.

**Regenerator.** – A device used in a thermodynamic process for capturing and returning to the process heat that would otherwise be lost. Also called 'a heat exchanger'.

**Relative Humidity (abbr rh).** – The (dimensionless) ratio of the actual vapor pressure of the air to the saturation vapor pressure.

**Relativistic.** – In general, pertaining to material, as a subatomic particle, moving at speeds which are an appreciable fraction of the speed of light.

**Relativity.** – A principle that postulates the equivalence of the description of the universe, in terms of physical laws, by various observers, or for various frames of reference.

**Reliability.** – The probability that a system, subsystem, component, or part will perform its required functions under defined conditions at a designated time and for a specified operating period.

**Reliability Program.** – A process designed to maximize chances for mission success by establishing a high degree of confidence in the operation of systems, subsystems, components, and parts through quality control.

**Rendezvous.** – The event of two or more objects meeting at a preconceived time and place.

*A rendezvous would be involved, for example, in servicing or resupplying a space station.*

**Resonance.** – 1. The phenomenon of amplification of a free wave or oscillation of a system by a forced wave or oscillation of exactly equal period. The forced wave may arise from an impressed force upon the system or from a boundary condition. The growth of the resonant amplitude is characteristically linear in time. 2. Of a system in forced oscillation, the condition which exists when any change, however small, in the frequency of excitation causes a decrease in the response of the system.

**Resonant Frequency.** – A frequency at which resonance exists.

In case of possible confusion, the type of resonance must be indicated; as 'velocity resonant frequency'.

**Retrograde.** – Having a direction contrary to that of the general course of planetary orbits. Also, directed from east to west.

**Retrorocket.** – (From 'retroacting'.) A rocket fitted on or in a spacecraft, satellite, or the like to produce thrust opposed to forward motion.

**Reverberation Chamber.** – An enclosure which has substantially complete sound reflection over its boundaries. Contrast with anechoic chamber.

**Revolution.** – Motion of a celestial body in its orbit; circular motion about an axis usually external to the body.

*In some contexts the terms 'revolution' and 'rotation' are used interchangeably; but with reference to the motions of a celestial body, 'revolution' refers to the motion in an orbit or about an axis external to the body, while 'rotation' refers to motion about an axis within the body. Thus, the earth revolves about the sun annually and rotates about its axis daily.*

**Rocket.** – 1. A projectile, pyrotechnic device, or flying vehicle propelled by a rocket engine. 2. A rocket engine.

**Rocket Engine.** – A reaction engine that contains within itself, or carries along with itself, all the substances necessary for its operation or for the consumption or combustion of its fuel, not requiring intake of any outside substance and hence capable of operation in outer space. Also called 'Rocket Motor'.

**Rocket Propellant.** – Any agent used for consumption or combustion in a rocket and from which the rocket derives its thrust, such as a fuel, oxidizer, additive, catalyst, or any compound or mixture of these. 'Rocket propellant' is often shortened to 'propellant'.

**Rocketsonde.** – Meteorological rocket.

**Roll.** – The rotational or oscillatory movement of an aircraft or similar body which takes place about a longitudinal axis through the body-called 'roll' for any amount of such rotation.

**Rotation.** – Turning of a body about an axis within the body, as the daily rotation of the earth. See **Revolution.**

**Rumble.** – A form of combustion instability, especially in a liquid-propellant rocket engine, characterized by a low-pitched, low-frequency rumbling noise; the noise made in this kind of combustion.

**Satellite.** – 1. An attendant body that revolves about another body, the primary; especially in the solar system, a secondary body, or moon, that revolves about a planet. 2. A man-made object that revolves about a spatial body, such as Explorer I orbiting about the earth.

**Screaming.** – A form of combustion instability, especially in a liquid-propellant rocket engine, of relatively high frequency and characterized by a high-pitched noise.

**Scrub.** – To cancel a scheduled rocket firing, either before or during countdown.

**Secondary Cosmic Rays.** – Secondary emission in the atmosphere stimulated by primary cosmic rays.

**Secular.** – Of the nature of a long enduring process.

*For example, the long term deviations in the surface magnetic field of the earth, which are in the magnitude of two tenths of one per cent per year, are called the secular change in the magnetic field.*

**Selenocentric.** – Relating to the center of the moon; referring to the moon as a center.

**Selenographic.** – 1. Of or pertaining to the physical geography of the moon. 2. Specifically, referring to positions on the moon measured in latitude from the moon's equator and in longitude from a reference meridian.

**Sensible Atmosphere.** – That part of the atmosphere that offers resistance to a body passing through it. See **Effective Atmosphere.**

**Sensor.** – The component of an instrument that converts an input signal into a quantity which is measured by another part of the instrument. Also called 'sensing element'.

**Service Tower** = **Gantry Scaffold.**

**Shaker.** – An electromagnetic device capable of imparting known, and/or controlled vibratory acceleration to a given object.

**Shield.** – Short for 'radiation shield'; 'heat shield'.

**Shot.** – An act or instance of firing a rocket, especially from the earth's surface, as 'the shot carried the rocket 200 miles'.

**Shroud.** – The nosecone of a space vehicle when it is used only as a shield for passage through the atmosphere from launch to orbit. It is usually jettisoned when orbital speed is achieved.

**Sidereal.** – Of or pertaining to the stars.

**Sinusoidal Vibration.** – An example of harmonic motion such that when the displacement of the body is plotted as a function of time, the plot produces a circular sine wave. Compare random vibıation and combustion resonance.

*In the sinusoidal vibration phase of spacecraft environmental testing, the specified range of frequencies is swept at prescribed rates. Constant acceleration is maintained by varying the input force.*

*Swept sinusoidal vibration simulates one aspect of the vibration experienced by spacecraft in the launch phase of space missions.*

**Sloshing.** – The back-and-forth splashing of a liquid fuel in its tank, creating problems of stability and control in the vehicle.

**Slug.** – A unit of mass; the mass of a free body which if acted upon by a force of 1 pound would experience an acceleration of 1 foot per second per second.

**Slurry.** – A suspension of fine solid particles in a liquid

**Soft Radiation.** – Radiation which is absorbed by an absorber equivalent to 10 centimeters of lead or less.

Radiation which can penetrate more than 10 centimeters of lead is termed 'hard radiation'.

**Solar Cell.** – A photovoltaic device that converts sunlight directly into electrical energy.

**Solar Constant.** – The rate at which solar radiation is received on a surface perpendicular to the incident radiation and at the earth's mean distance from the sun, but outside the earth's atmosphere.

**Solar Radiation.** – The total electromagnetic radiation emitted by the sun.

**Solar Simulator.** – A source of light which is designed to simulate the intensity and spectrum of the sun.

*In spacecraft environmental testing, it is usually used in conjunction with a vacuum chamber in order to simulate the sun's effect on spacecraft in the vacuum of space.*

**Solar Wind.** – A stream of protons constantly moving outward from the sun.

**Solid Propellant.** – Specifically, a rocket propellant in solid form, usually containing both fuel and oxidizer combined or mixed and formed into a monolithic (not powdered or granulated) grain. See **Rocket Propellant** and **Grain.**

**Solid-Propellant Rocket Engine.** – A rocket engine using a solid propellant. Such engines consist essentially of a combustion chamber containing the propellant, and a nozzle for the exhaust jet, although they often contain other components, as grids, liners, etc. See **Rocket Engine** and **Solid Propellant.**

**Sophisticated.** – Complex and intricate; making use of advanced art; requiring special skills to operate.

**Sounding.** – 1. In geophysics, any penetration of the natural environment for scientific observation. 2. In meteorology, same as upper-air observation. However, a common connotation is that of a single complete radiosonde observation.

**Sounding Rocket.** – A rocket designed to explore the atmosphere within 4,000 miles of the earth's surface.

**Space.** – 1. Specifically, the part of the universe lying outside the limits of the earth's atmosphere. 2. More generally, the volume in which all spatial bodies, including the earth, move.

**Space-Air Vehicle.** – A vehicle that may be operated either within or above the sensible atmosphere.

**Spacecraft.** – Devices, manned or unmanned, which are designed to be placed into an orbit about the earth or into a trajectory to another celestial body.

**Space Equivalent.** – A condition within the earth's atmosphere that is virtually identical, in terms of a particular function, with a condition in outer space.

*For example, at 50,000 feet the low air pressure and the scarcity of oxygen create a condition, so far as respiration is concerned, that is equivalent to a condition in outer space where no appreciable oxygen is present; thus, a physiological space equivalent is present in the atmosphere.*

**Space Probe.** – See **Probe.**

**Space Simulator.** – A device which simulates some condition or conditions existing in space and used for testing equipment, or in training programs.

**Space System.** – A system consisting of launch vehicle(s), spacecraft and ground support equipment.

**Space Vehicle.** – A launch vehicle and its associated spacecraft.

**Specific Impulse.** – A performance parameter of a rocket propellant, expressed in seconds, and equal to thrust (in pounds) divided by weight flow rate (in pounds per second). See **Thrust.**

**Spectrometer.** – An instrument which measures some characteristics such as intensity, of electromagnetic radiation as a function of wavelength or frequency.

**Spectrum.** – 1. In physics, any series of energies arranged according to wavelength (or frequency); specifically, the series of images produced when a beam of radiant energy, such as sunlight, is dispersed by a prism or a reflecting grating. 2. Short for 'electromagnetic spectrum' or for any part of it used for a specific purpose as the 'radio spectrum' (10 kilocycles to 300,000 megacycles).

**Sputtering.** – Dislocation of surface atoms of a material bombarded by high-energy atomic particles.

**Stage.** – A propulsion unit of a rocket, especially one unit of a multistage rocket, including its own fuel and tanks.

**Stage-and-a-Half.** – A liquid-rocket propulsion unit of which only part falls away from the rocket vehicle during flight, as in the case of booster rockets falling away to leave the sustainer engine to consume remaining fuel.

**Standard Atmosphere.** – 1. A hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and rocket design, ballistic tables, etc.

2. A standard unit of atmospheric pressure exerted by a 760 mm column of mercury at gravity (980.665 cm/sec$^2$) at temperature O°C.

$$\begin{aligned}\text{One standard atmosphere} &= 760 \text{ mm Hg}\\ &= 29.9213 \text{ in. Hg}\\ &= 1013.250 \text{ mb}\end{aligned}$$

**Static Balance.** – The absence of displacement of the center of gravity from the spin or thrust axis of a spacecraft. During spacecraft environmental testing, weights are added or shifted to attain a close approximation of this condition while spacecraft is stationary. Contrast with dynamic balance.

**Stationary Orbit.** – An orbit in which an equatorial satellite revolves about the primary at the same angular rate as the primary rotates on its axis. From the primary, the satellite thus appears to be stationary over a point on the primary.

**Stefan-Boltzmann Law.** – One of the radiation laws which states that the amount of energy radiated per unit time from a unit surface area of an ideal black body is proportional to the fourth power of the absolute temperature of the black body.

**Strain Gage.** – An instrument used to measure the strain or distortion in a member or test specimen (such as a structural part) subjected to a force.

**Structural Model Test.** – Tests prior to design qualification which subject the structural model of the spacecraft to exposures of spin, acceleration, and vibration at design qualification level to establish confidence in the structural design.

**Subassembly.** – An assembly within a larger assembly.

**Subsystem.** – A functioning entity within a major system (launch vehicle, spacecraft, etc.) of a space system such as propulsion subsystem of a launch vehicle or attitude control subsystem of a spacecraft. Also considered a system.

**Sudden Ionospheric Disturbance.** – (Often abbreviated SID). A complex combination of sudden changes in the condition of the ionosphere, and the effects of these changes.

**Sunspot.** – A relatively dark area on the surface of the sun, consisting of a dark central umbra surrounded by a penumbra which is intermediate in brightness between the umbra and the surrounding photosphere.

Sunspots usually occur in pairs with opposite magnetic polarities. They have a lifetime ranging from a few days to several months. Their occurrence exhibits approximately an eleven year period (the sunspot cycle).

**Sunspot Cycle.** – A cycle with an average length of 11.1 years, but varying between about 7 and 17 years, in the number and area of sunspots, as given by the relative sunspot number. This number rises from a minimum of 0-10 to a maximum of 50-140 about four years later, and then declines more slowly.

An approximate 11-year cycle has been found or suggested in geomagnetism, frequency of aurora, and other ionospheric characteristics.

Eleven-year cycles have been suggested for various tropospheric phenomena, but none of these has been substantiated.

**Sustainer Engine.** – An engine that maintains the velocity of a missile rocket vehicle once it has achieved its programmed velocity by use of booster or other engine.

This term is applied, for example, to the remaining engine of the Atlas after the two booster engines have been jettisoned. The term is also applied to a rocket engine used on an orbital glider to provide the small amount of thrust now and then required to compensate for the drag imparted by air particles in the upper atmosphere.

**Sweep.** – The motion of the visible dot across the face of a cathode-ray tube, as a result of scanning deflection of the electron beam.

**Synchronous Satellite.** – An equatorial west-to-east satellite orbiting the earth at an altitude of 22,300 statute miles at which altitude it makes one revolution in 24 hours, synchronous with the earth's rotation.

**System.** – 1. An organized arrangement in which the operational results of two or more functioning entities can be predicted.

2. Used in term, space system, to mean the launch vehicle, spacecraft and ground support used in a space launch and flight.

3. One of major subdivisions of a space system, such as launch vehicle, spacecraft, or ground support system.

4. One of major functioning entities within a major subdivision of a space system, such as the guidance system of a launch vehicle or the attitude control system of a spacecraft.

In sense 4, synonymous with subsystem.

**Systems Integration.** – The management process by which the systems of a project (for example, the launch vehicle, the spacecraft, and its supporting ground equipment and operational procedures) are made compatible, in order to achieve the purpose of the project or the given flight mission.

**Telemetry.** – The science of measuring a quantity or quantities, transmitting the measured value to a distant station, and there interpreting, indicating, or recording the quantities measured.

**Terminator.** – The line separating illuminated and dark portions of a nonluminous body, as the moon.

**Terrestrial.** – Pertaining to the earth.

**Test.** – A procedure or action taken to determine under real or simulated conditions the capabilities, limitations, characteristics, effectiveness, reliability, or suitability of a material, device, system, or method.

**Test Chamber.** – A place, section, or room having special characteristics where a person or object is subjected to experiment, such as an altitude chamber; specifically, the test section of a wind tunnel.

**Test Stand.** – A stationary platform or table, together with any testing apparatus attached thereto, for testing or proving engines, instruments, etc. See **Proving Stand.**

**Thermal.** – Pertaining to heat or temperature.

**Thermocouple.** – A temperature-sensing element which converts thermal energy directly into electrical energy. In its basic form it consists of two dissimilar metallic electrical conductors connected in a closed loop. Each junction forms a thermocouple.

If one thermocouple is maintained at a temperature different from that of the other, an electrical current proportional to this temperature difference will flow in the circuit; the value of this proportionality varies with materials used. For meteorological purposes, couples of copper and constantan are frequently used which generate approximately 40 microvolts per °C of couple temperature difference.

**Thermodynamic.** – Pertaining to the flow of heat or to thermodynamics.

**Thermodynamics.** – The study of the relationships between heat and mechanical energy.

**Thermonuclear.** – Pertaining to a nuclear reaction that is triggered by particles of high thermal energy.

**Thrust.** – 1. The pushing force developed by an aircraft engine or a rocket engine. 2. Specifically, in rocketry, the product of propellant mass flow rate and exhaust velocity relative to the vehicle.

**Tore or Torus.** – In geometry the surface described by a conic section, especially a circle, rotating about a straight line in its own plane or the solid or revolution enclosed by such a surface. Hence, the extended sections of a manned space laboratory, having a generally circular configuration and rotating around a stationary central section.

**Torr. (From Torricelli).** – Suggested international standard term to replace the English term 'millimeter of mercury' and its abbreviation 'mm of Hg' (or the French 'mm de Hg').

Both 'Tor' and 'Torr' have been used in Germany, the latter spelling being more common and the one officially adopted by the German Standards Association. The 'Torr' is defined as 1/760 of a standard atmosphere or 1,013,250/760 dynes per square centimeter. This is equivalent to defining the 'Torr' as 1333.22 microbars and differs by only one part in seven million from the International Standard millimeter of mercury. It is recommended that 'Torr' not be abbreviated. However, the abbreviation $\tau$ has been used. The prefixes 'milli' and 'micro' are attached without hyphenation.

**Tracking.** – The process of following the movement of a satellite or rocket by radar, radio, and photographic observations.

**Trajectory.** – In general, the path traced by any body, as a rocket, moving as a result of externally applied forces.

*Trajectory is loosely used to mean 'flight path' or 'orbit'.*

**Transducer.** – A device capable of being actuated by energy from one or more transmission systems or media, as a microphone, a thermocouple, etc.

**Transfer Orbit.** – In interplanetary travel an elliptical trajectory tangent to the orbits of both the departure planet and the target planet.

**Transit.** – 1. The passage of a celestial body across a celestial meridian; usually called 'meridian transit'. 2. The apparent passage of a celestial body across the face of another celestial body or across any point, area, or line.

**Translunar.** – Of or pertaining to space outside the moon's orbit about the earth.

**Transmissibility.** – The ratio of the response amplitude of a system in steady-state forced vibration to the excitation amplitude, the ratio may be one of forces, displacements, velocities, or accelerations.

**Transponder.** – A combined receiver and transmitter whose function is to transmit signals automatically when triggered by an interrogating signal.

**Transponder Beacon.** – A beacon having a transponder.

**T-Time.** – Any specific time, minus or plus, as referenced to 'zero', or 'launch' time, during a countdown sequence that is intended to result in the firing of a rocket propulsion unit that launches a rocket vehicle or missile.

**Troposphere.** – That portion of the atmosphere from the earth's surface to the tropopause; that is, the lowest 10 to 20 km of the atmosphere. The troposphere is characterized by decreasing temperature with height, appreciable vertical wind motion, appreciable water vapor content, and weather. Dynamically, the troposphere can be divided into the following layers: surface boundary layer, Ekman layer, and free atmosphere.

**Ullage.** – The amount that a container, such as a fuel tank, lacks of being full.

**Ultraviolet Radiation.** – Electromagnetic radiation shorter in wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 100 and 4000 angstroms.

*Ultraviolet radiation from the sun is responsible for many complex photochemical reactions characteristic of the upper atmosphere, e.g., the formation of the ozone layer through ultraviolet dissociation of oxygen molecules followed by recombination to form ozone.*

**Umbilical Cord.** – Any of the servicing electrical or fluid lines between the ground or a tower and an upright rocket missile or vehicle before the launch. Often shortened to 'umbilical'.

**Upper-Air Observation.** – A measurement of atmospheric conditions aloft, above the effective range of a surface weather observation. Also called 'sounding', 'upper-air sounding'.

**Van Allen Belt, Van Allen Radiation Belt.** – [For James A. Van Allen, 1915-.] The zone of high-energy particles surrounding the earth beginning at altitudes of approximately 1000 kilometers.

The Van Allen belt is composed of protons and electrons temporarily trapped in the earth's magnetic field. The concentration varies with the distance from the earth.

**Vehicle.** – Specifically, a structure, machine, or device, such as an aircraft or rocket, designed to carry a burden through air or space; more restrictively, a rocket craft.

*This word has acquired its specific meaning owing to the need for a term to embrace all flying craft, including aircraft and rockets.*

**Vehicle Control System.** – A system, incorporating control surfaces or other devices, which adjusts and maintains the altitude and heading, and sometimes speed, of the vehicle in accordance with signals received from a guidance system.

The essential difference between a control system and a guidance system is that the control system points the vehicle and the guidance system gives the commands which tell the control system where to point. However, the control system maintains the instantaneous orientation of the vehicle without specific commands from the guidance system.

**Vernier Engine.** – A rocket engine of small thrust used primarily to obtain a fine adjustment in the velocity and trajectory of a ballistic missile or space vehicle just after the thrust cutoff of the last propulsion engine, and used secondarily to add thrust to a booster or sustainer engine. Also called 'vernier rocket'.

**Vertical.** – The direction in which the force of gravity acts.

**Viscous Damping.** – The dissipation of energy that occurs when a particle in a vibrating system is resisted by a force that has a magnitude proportional to the magnitude of the velocity of the particle and direction opposite to the direction of the particle.

**Visible Radiation.** – Electromagnetic radiation lying within the wavelength interval to which the human eye is sensitive, which is from approximately 0.4 to 0.7 micron (4000 to 7000 angstroms). This portion of the electromagnetic spectrum is bounded on the shortwavelength end by ultraviolet radiation, and on the longwavelength end by infrared radiation.

**Waiver.** – Granted use or acceptance of an article which does not meet specified requirements.

**Waveguide.** – A system of material boundaries capable of guiding electromagnetic waves.

**Weight.** – The force with which an earth-bound body is attracted toward the earth.

**Weightlessness.** – Besides describing the absence of gravity, this term is also used to describe a condition in which no acceleration, whether of gravity or other force, can be detected by an observer within the system in question.

*Any object falling freely in a vacuum is weightless, thus a satellite orbiting the earth is 'weightless' although gravity effects its orbit. Weightlessness can be produced within the atmosphere in aircraft flying a parabolic flight path.*

**White Noise.** – A noise whose power spectral density is substantially independent of frequency over a specified range. See **Power Spectral Density.**

**X-Ray.** – Electromagnetic radiation of very short wavelength, lying within the wavelength interval of 0.1 to 100 angstroms (between gamma rays and ultraviolet radiation, 'Roentgen ray').

*X-rays penetrate various thickness of all solids and they act upon photographic plates in the same manner as light. Secondary X-rays are produced whenever X-rays are absorbed by a substance, in the case of absorption by a gas, this results in ionization.*

**Yaw.** – 1. The lateral rotational or oscillatory movement of an aircraft, rocket, or the like about a transverse axis. 2. The amount of this movement, i.e., the angle of yaw.

**Year of the Quiet Sun.** – Eleven year low period in solar activity which is expected between April, 1964 and December, 1965. The international program for maximum observation and research in this interval is termed International Year of the Quiet Sun (IQSY).

**Zenith.** – That point of the celestial sphere vertically overhead.
The point 180° from the zenith is called the 'nadir'.

**Zero G** = **Weightlessness.**

# B

# INTERNATIONAL LOG OF SPACE LAUNCHES

# INTERNATIONAL LOG OF SPACE LAUNCHES◆

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Sputnik 1 | 1957 Alpha 2 | USSR | Oct 4, 1957 | Unknown | Unknown | 184 | 96.2 | 141 | 588 | 65.1 | Re-entered Dec 1, 1957 (57 days) |
| Sputnik 2 | 1957 Beta | USSR | Nov 3, 1957 | Unknown | Unknown | 1120 | 103.7 | 140 | 1038 | 65.3 | Re-entered April 14, 1958 (162 days) |
| Vanguard TV 3* | None | USN | Dec 6, 1957 | AMR | Vanguard | 3 | — | — | — | — | Failed to orbit |
| Explorer 1 | 1958 Alpha | USA | Jan 31, 1958 | AMR | Jupiter C | 31 | 114.7/105.3 | 224/221 | 1584/1043 | 33.3/33.2 | In orbit (silent) |
| Vanguard TV 3* backup | None | USN | Feb 5, 1958 | AMR | Vanguard | 3 | — | — | — | — | Failed to orbit |
| Explorer 2 | None | USA | March 5, 1958 | AMR | Jupiter C | 32 | — | — | — | — | Failed to orbit |
| Vanguard 1 | 1958 Beta 2 | USN | March 17, 1958 | AMR | Vanguard | 3 | 134.3/133.8 | 405/408 | 2462/2444 | 34.3/34.2 | In orbit (active) |
| Explorer 3 | 1958 Gamma | USA | March 26, 1958 | AMR | Jupiter C | 31 | 114.7 | 117 | 1739 | 33.5 | Re-entered June 28, 1958 (94 days) |
| Vanguard TV 5* | None | USN | April 28, 1958 | AMR | Vanguard | 22 | — | — | — | — | Failed to orbit |
| Sputnik 3 | 1958 Delta 2 | USSR | May 15, 1958 | Unknown | Unknown | 2925 | 105.8 | 140 | 1168 | 65.2 | Re-entered April 6, 1960 (692 days) |
| Vanguard SLV 1†† | None | USN | May 27, 1958 | AMR | Vanguard | 22 | — | — | — | — | Failed to orbit |
| Vanguard SLV 2†† | None | USN | June 26, 1958 | AMR | Vanguard | 22 | — | — | — | — | Failed to orbit |
| Explorer 4 | 1958 Epsilon | ARPA | July 26, 1958 | AMR | Jupiter C | 38 | 110.1 | 163 | 1372 | 50.1 | Re-entered Oct 23, 1959 (454 days) |
| Able 1 Project (Pioneer) | None | USAF | Aug 17, 1958 | AMR | Thor-Able | 84 | — | — | — | — | Lunar probe: failed to orbit |
| Explorer 5 | None | ARPA | Aug 24, 1958 | AMR | Jupiter C | 38 | — | — | — | — | Failed to orbit |
| Vanguard SLV 3†† | None | USN | Sept 26, 1958 | AMR | Vanguard | 22 | — | — | — | — | Failed to orbit |
| Pioneer 1 | None | NASA | Oct 11, 1958 | AMR | Thor-Able | 84 | — | — | — | — | Lunar probe: reached altitude of 70,700 miles |
| Beacon 1 | None | NASA | Oct 23, 1958 | AMR | Jupiter C | 28 | — | — | — | — | Failed to orbit |
| Pioneer 2 | None | NASA | Nov 8, 1958 | AMR | Thor-Able | 87 | — | — | — | — | Lunar probe: reached altitude of 963 miles |
| Pioneer 3 | None | NASA | Dec 6, 1958 | AMR | Juno II | 13 | — | — | — | — | Lunar probe: reached altitude of 63,580 miles |
| Project Score | 1958 Zeta | ARPA | Dec 18, 1958 | AMR | Atlas | 8750 | 101.5 | 115 | 914 | 32.3 | Re-entered Jan 21, 1959 (34 days) |
| Lunik 1 | 1959 Mu | USSR | Jan 2, 1959 | Unknown | Unknown | 3245 | 450 days | 0.9766 AU** | 1.315 AU | 0.01††† | Lunar probe: in solar orbit (silent) |
| Vanguard 2 | 1959 Alpha 1 | NASA | Feb 17, 1959 | AMR | Vanguard | 22 | 125.9/125.2 | 347/348 | 2064/2039 | 32.9/32.9 | In orbit (silent) |
| Discoverer 1 | 1959 Beta | ARPA | Feb 28, 1959 | VAFB | Thor-Agena A | 1300 | 94.1 | 184 | 407 | 90.0 | Re-entered in early March, 1959; no re-entry capsule carried |
| Pioneer 4 | 1959 Nu | NASA | March 3, 1959 | AMR | Juno II | 13 | 398 days | 0.9871 AU** | 1.142 AU | 0.130††† | Lunar probe: in solar orbit (silent) |

*TV: Test Vehicle
†† SLV: Satellite Launching Vehicle

AMR: Atlantic Missile Range
PA: Point Arguello
WI: Wallops Island
VAFB: Vandenberg Air Force Base

** Astronomical Units
††† Inclination from the ecliptic

Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Discoverer 2 | 1959 Gamma | ARPA | April 13, 1959 | VAFB | Thor-Agena A | 1600 | 90.6 | 152 | 225 | 90.0 | Re-entered April 26, 1959 (13 days); capsule ejected, no recovery |
| Vanguard SLV 5†† | None | NASA | April 13, 1959 | AMR | Vanguard | 23 | — | — | — | — | Failed to orbit |
| Discoverer 3 | None | ARPA | June 3, 1959 | VAFB | Thor-Agena A | 1600 | — | — | — | — | Failed to orbit |
| Vanguard SLV 6†† | None | NASA | June 22, 1959 | AMR | Vanguard | 23 | — | — | — | — | Failed to orbit |
| Discoverer 4 | None | ARPA | June 25, 1959 | VAFB | Thor-Agena A | 1700 | — | — | — | — | Failed to orbit |
| Explorer Project | None | NASA | July 16, 1959 | AMR | Juno II | 92 | — | — | — | — | Destroyed by range safety officer |
| Explorer 6 (S-2) | 1959 Delta 1 | NASA (GSFC) | Aug 7, 1959 | AMR | Thor-Able | 143 | 768 | 157 | 26,366 | 47.0 | Re-entered prior to July, 1961 |
| Discoverer 5 | 1959 Epsilon 1 | ARPA | Aug 13, 1959 | VAFB | Thor-Agena A | 1700 | 94.1 | 135 | 456 | 80.0 | Re-entered Sept 28, 1959 (47 days); capsule ejected into separate orbit |
| Beacon 2 | None | NASA | Aug 14, 1959 | AMR | Juno II | 84 | — | — | — | — | Failed to orbit |
| Discoverer 6 | 1959 Zeta | ARPA | Aug 19, 1959 | VAFB | Thor-Agena A | 1700 | 95.2 | 131 | 528 | 84.0 | Re-entered Oct 20, 1959 (63 days); capsule ejected, no recovery |
| Lunik 2 | 1959 Xi | USSR | Sept 12, 1959 | Unknown | Unknown | 858 | N/A*† | N/A | N/A | N/A | Lunar probe: impacted on moon Sept 13, 1959 (flight time: 33.5 hours) |
| Transit 1A | None | ARPA | Sept 17, 1959 | AMR | Thor-Able | 265 | — | — | — | — | Failed to orbit |
| Vanguard 3 | 1959 Eta | NASA (GSFC) | Sept 18, 1959 | AMR | Vanguard | 100 | 130.2/129.7 | 317/332 | 2329/2301 | 33.3/33.3 | In orbit (silent) |
| Lunik 3 | 1959 Theta | USSR | Oct 4, 1959 | Unknown | Unknown | 614 | 16.2 days | 25,257 | 291,439 | 76.8 | Lunar probe: passed around moon into earth orbit, re-entered April 20, 1960 (199 days) |
| Explorer 7 (S-1a) | 1959 Iota 1 | NASA (GSFC) | Oct 13, 1959 | AMR | Juno II | 92 | 101.2/101.1 | 346/354 | 676/658 | 50.3/50.3 | In orbit (silent) |
| Discoverer 7 | 1959 Kappa | ARPA | Nov 7, 1959 | VAFB | Thor-Agena A | 1700 | 94.6 | 99 | 519 | 81.6 | Re-entered Nov 26, 1959 (19 days); malfunction prevented capsule ejection |
| Discoverer 8 | 1959 Lambda | USAF | Nov 20, 1959 | VAFB | Thor-Agena A | 1700 | 103.7 | 120 | 1032 | 80.6 | Re-entered March 8, 1960 (110 days); capsule ejected, no recovery |
| Atlas-Able 4 (Pioneer) | None | NASA | Nov 26, 1959 | AMR | Atlas-Able | 372 | — | — | — | — | Lunar probe: failed to orbit |
| Discoverer 9 | None | USAF | Feb 4, 1960 | VAFB | Thor-Agena A | 1700 | — | — | — | — | Failed to orbit |
| Discoverer 10 | None | USAF | Feb 19, 1960 | VAFB | Thor-Agena A | 1700 | — | — | — | — | Destroyed by range safety officer |
| Midas 1 | None | USAF | Feb 26, 1960 | AMR | Atlas-Agena A | 35 | — | — | — | — | Failed to orbit |
| Pioneer 5 | 1960 Alpha | NASA (GSFC) | March 11, 1960 | AMR | Thor-Able | 95 | 311.6 days | 0.8061 AU** | 0.995 AU | 3.35††† | Interplanetary probe: in solar orbit (silent) |

†† SLV: Satellite Launching Vehicle *† N/A: not applicable ** Astronomical Units ††† Inclination from the ecliptic

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Explorer Radiation Satellite | None | NASA | March 23, 1960 | AMR | Juno II | 35 | — | — | — | — | Failed to orbit |
| Tiros 1 | 1960 Beta 2 | NASA (GSFC) | April 1, 1960 | AMR | Thor-Able | 270 | 99.2/99.1 | 430/423 | 468/472 | 48.3/48.4 | In orbit (silent) |
| Transit 1B | 1960 Gamma 2 | ARPA | April 13, 1960 | AMR | Thor-Able Star | 265 | 95.8/94.3 | 232/216 | 463/394 | 51.3/51.2 | In orbit (silent) |
| Discoverer 11 | 1960 Delta | USAF | April 15, 1960 | VAFB | Thor-Agena A | 1700 | 92.3 | 103 | 375 | 80.1 | Re-entered April 26, 1960 (11 days); capsule ejected, no recovery |
| Project Echo | None | NASA (GSFC) | May 13, 1960 | AMR | Delta | 132 | — | — | — | — | Failed to orbit |
| Sputnik 4 | 1960 Epsilon 1 | USSR | May 15, 1960 | Unknown | Unknown | 10,008 | 91.3 | 194 | 229 | 65 | Re-entered Sept 5, 1962 (843 days) |
| Midas 2 | 1960 Zeta 1 | USAF | May 24, 1960 | AMR | Atlas-Agena A | 5000 | 94.4/94.2 | 299/281 | 321/324 | 33.0/33.0 | In orbit (silent) |
| Transit 2A<br>Greb 1 | 1960 Eta 1<br>1960 Eta 2 | USN | June 22, 1960 | AMR | Thor-Able Star | 223<br>42 | 101.7/101.6<br>101.6/101.6 | 389/377<br>382/377 | 665/661<br>657/660 | 66.7/66.7<br>66.8/66.7 | In orbit (active upon command)<br>In orbit (silent) |
| Discoverer 12 | None | USAF | June 29, 1960 | VAFB | Thor-Agena A | 1700 | — | — | — | — | Failed to orbit |
| Discoverer 13 | 1960 Theta | USAF | Aug 10, 1960 | VAFB | Thor-Agena A | 1700 | 94.1 | 157 | 431 | 82.8 | Re-entered Nov 14, 1960 (96 days); capsule recovered from ocean |
| Echo 1 | 1960 Iota 1 | NASA (GSFC) | Aug 12, 1960 | AMR | Delta | 166 | 118.2/115.4 | 941/588 | 1052/1246 | 47.2/47.3 | In orbit (silent) |
| Discoverer 14 | 1960 Kappa | USAF | Aug 18, 1960 | VAFB | Thor-Agena A | 1700 | 94.5 | 113 | 502 | 79.6 | Re-entered Sept 16, 1960 (29 days); capsule recovered in air |
| Courier 1A | None | ARPA | Aug 18, 1960 | AMR | Thor-Able Star | 500 | — | — | — | — | Failed to orbit |
| Sputnik 5 | 1960 Lambda 1 | USSR | Aug 19, 1960 | Unknown | Unknown | 10,120 | 90.7 | 190 | 211 | 64.9 | Re-entered Aug 20, 1960 (1 day); capsule recovered on land |
| Discoverer 15 | 1960 Mu | USAF | Sept 13, 1960 | VAFB | Thor-Agena A | 1700 | 94.2 | 125 | 469 | 80.9 | Re-entered Oct 18, 1960 (35 days); capsule ejected, no recovery |
| Atlas-Able 5A (Pioneer) | None | NASA | Sept 25, 1960 | AMR | Atlas-Able | 387 | — | — | — | — | Lunar probe: failed to orbit |
| Courier 1B | 1960 Nu 1 | USA | Oct 4, 1960 | AMR | Thor-Able Star | 500 | 106.9/106.9 | 586/593 | 767/761 | 28.3/28.4 | In orbit (silent) |
| None | None | USSR | Oct 10, 1960 | Unknown | Unknown | Unknown | — | — | — | — | Mars probe: failed to orbit |
| Samos 1 | None | USAF | Oct 11, 1960 | PA | Atlas-Agena A | 4100 | — | — | — | — | Failed to orbit |
| None | None | USSR | Oct 14, 1960 | Unknown | Unknown | Unknown | — | — | — | — | Mars probe: failed to orbit |
| Discoverer 16 | None | USAF | Oct 26, 1960 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Failed to orbit |
| Explorer 8 (S-30) | 1960 Xi 1 | NASA (GSFC) | Nov 3, 1960 | AMR | Juno II | 90 | 112.7/112.4 | 285/262 | 1422/1403 | 50.0/50.0 | In orbit (silent) |
| Discoverer 17 | 1960 Omicron | USAF | Nov 12, 1960 | VAFB | Thor-Agena B | 2100 | 96.4 | 113 | 614 | 81.9 | Re-entered Dec 29, 1960 (48 days); capsule recovered in air |

AMR: Atlantic Missile Range
PA: Point Arguello
WI: Wallops Island
VAFB: Vandenberg Air Force Base

Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Tiros 2 | 1960 Pi 1 | NASA (GSFC) | Nov 23, 1960 | AMR | Delta | 280 | 98.3/98.2 | 387/369 | 452/469 | 48.5/48.5 | In orbit (silent) |
| Transit 3A/Greb 2 | None | USN | Nov 30, 1960 | AMR | Thor-Able Star | 203/40 | — | — | — | — | Destroyed by range safety officer |
| Sputnik 6 | 1960 Rho 1 | USSR | Dec 1, 1960 | Unknown | Unknown | 10,060 | 88.6 | 116 | 165 | 65 | Re-entered Dec 2, 1960 (1 day); capsule destroyed in re-entry |
| Scout 3 (Explorer) | None | NASA | Dec 4, 1960 | WI | Scout | 87 | — | — | — | — | Failed to orbit |
| Discoverer 18 | 1960 Sigma | USAF | Dec 7, 1960 | VAFB | Thor-Agena B | 2100 | 93.8 | 143 | 426 | 80.8 | Re-entered April 2, 1961 (115 days); capsule recovered in air |
| Atlas-Able 5B (Pioneer) | None | NASA | Dec 15, 1960 | AMR | Atlas-Able | 388 | — | — | — | — | Lunar probe: failed to orbit |
| Discoverer 19 | 1960 Tau | USAF | Dec 20, 1960 | VAFB | Thor-Agena B | 2100 | 93.0 | 128 | 390 | 82.8 | Re-entered Jan 23, 1961 (34 days); no re-entry capsule carried |
| Samos 2 | 1961 Alpha 1 | USAF | Jan 31, 1961 | PA | Atlas-Agena A | 4100 | 95/94.8 | 300/287 | 350/344 | 97/97.4 | In orbit (silent) |
| Sputnik 7 | 1961 Beta 1 | USSR | Feb 4, 1961 | Unknown | Unknown | 14,292 | 89.8 | 139 | 204 | 65.0 | Re-entered Feb 26, 1961 (22 days) |
| Venus Probe | 1961 Gamma 1 | USSR | Feb 12, 1961 | Unknown | Unknown | 1419 | 300 days | 0.7183 AU** | 1.0190 AU | 0.58††† | Venus probe: in solar orbit (silent) Launched Venus Probe from parking orbit; re-entered Feb 25, 1961 (13 days) |
| Sputnik 8 | 1961 Gamma 2 | | | | | 14,292 | 89.7 | 123 | 198 | 65.0 | |
| Explorer 9 (S-56a) | 1961 Delta 1 | NASA (GSFC) | Feb 16, 1961 | WI | Scout | 17 | 118.3/117.5 | 395/424 | 1605/1535 | 38.6/38.8 | In orbit (silent) |
| Discoverer 20 | 1961 Epsilon 1 | USAF | Feb 17, 1961 | VAFB | Thor-Agena B | 2450 | 95.4 | 177 | 486 | 80.4 | Re-entered July 28, 1962 (526 days); malfunction prevented capsule ejection |
| Discoverer 21 | 1961 Zeta | USAF | Feb 18, 1961 | VAFB | Thor-Agena B | 2100 | 93.8 | 149 | 659 | 80.7 | Re-entered April 20, 1962 (426 days); no re-entry capsule carried |
| Transit 3B/Lofti | 1961 Eta | USN | Feb 21, 1961 | AMR | Thor-Able Star | 250/57 | 94.5 | 117 | 511 | 28.4 | Re-entered March 30, 1961 (37 days); failed to separate |
| Explorer S-45 1 | None | NASA | Feb 24, 1961 | AMR | Juno II | 74 | — | — | — | — | Failed to orbit |
| Sputnik 9 | 1961 Theta 1 | USSR | March 9, 1961 | Unknown | Unknown | 10,340 | | 114 | 155 | 64.9 | Spacecraft recovered on land (March 9, 1961) |
| Sputnik 10 | 1961 Iota 1 | USSR | March 25, 1961 | Unknown | Unknown | 10,330 | 88.4 | 111 | 153 | 64.9 | Spacecraft recovered on land (March 25, 1961) |
| Explorer 10 (P-14) | 1961 Kappa | NASA (GSFC) | March 25, 1961 | AMR | Delta | 79 | 112 hrs/ | 100/ | 145,000/ | 33/ | Present position uncertain |
| Discoverer 22 | None | USAF | March 30, 1961 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Failed to orbit |
| Discoverer 23 | 1961 Lambda 1 | USAF | April 8, 1961 | VAFB | Thor-Agena B | 2100 | 101.2 | 126 | 882 | 81.9 | Re-entered April 16, 1962 (373 days); capsule ejected into separate orbit |

AMR: Atlantic Missile Range
PA: Point Arguello
WI: Wallops Island
VAFB: Vandenberg Air Force Base

** Astronomical Units

††† Inclination from the ecliptic

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Vostok 1 | 1961 Mu 1 | USSR | April 12, 1961 | Baikonur | Unknown | 10,418 | 89.1 | 112 | 203 | 65.0 | Manned spacecraft recovered on land after 1 orbit (April 12, 1961) |
| Mercury-Atlas 3 | None | NASA | April 25, 1961 | AMR | Atlas D | 2000 | — | — | — | — | Destroyed by range safety officer |
| Explorer 11 (S-15) | 1961 Nu | NASA (GSFC) | April 27, 1961 | AMR | Juno II | 82 | 108.1/107.8 | 304/304 | 1113/1104 | 28.8/28.8 | In orbit (silent) |
| Explorer S-45 11 | None | NASA | May 24, 1961 | AMR | Juno II | 75 | — | — | — | — | Failed to orbit |
| Discoverer 24 | None | USAF | June 8, 1961 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Failed to orbit |
| Discoverer 25 | 1961 Xi | USAF | June 16, 1961 | VAFB | Thor-Agena B | 2100 | 90.9 | 139 | 251 | 82.1 | Re-entered July 12, 1961 (26 days); capsule recovered from ocean |
| Transit 4A<br>Injun/Greb 3 | 1961 Omicron 1<br>1961 Omicron 2 | USN | June 29, 1961 | AMR | Thor-Able Star | 175<br>55/40 | 103.7/103.8<br>103.8/103.8 | 534/546<br>534/546 | 623/621<br>634/622 | 67/66.8<br>67/66.8 | In orbit (active)<br>In orbit (active); failed to separate |
| Explorer S-55 | None | NASA | June 30, 1961 | WI | Scout | 187 | — | — | — | — | Failed to orbit |
| Discoverer 26 | 1961 Pi | USAF | July 7, 1961 | VAFB | Thor-Agena B | 2100 | 95 | 146 | 503 | 82.9 | Re-entered Dec 5, 1961 (151 days); capsule recovered in air |
| Tiros 3 | 1961 Rho 1 | NASA (GSFC) | July 12, 1961 | AMR | Delta | 285 | 100.4/100.3 | 461/474 | 506/492 | 47.8/47.9 | In orbit (silent) |
| Midas 3 | 1961 Sigma 1 | USAF | July 12, 1961 | PA | Atlas-Agena B | 3500 | 160/161.5 | 1850/2078 | 1850/2203 | 91.1/91.2 | In orbit |
| Discoverer 27 | None | USAF | July 21, 1961 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Destroyed by range safety officer |
| Discoverer 28 | None | USAF | Aug 3, 1961 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Failed to orbit |
| Vostok 2 | 1961 Tau 1 | USSR | Aug 6, 1961 | Baikonur | Unknown | 10,430 | 88.6 | 111 | 160 | 64.9 | Manned spacecraft recovered on land after 17 orbits (Aug 7, 1961) |
| Explorer 12 (S-3) | 1961 Upsilon | NASA (GSFC) | Aug 15, 1961 | AMR | Delta | 83 | 1585/ | 180/ | 47,800/ | 33.3/ | Present position uncertain |
| Ranger 1 | 1961 Phi 1 | NASA | Aug 23, 1961 | AMR | Atlas-Agena B | 675 | 91.1 | 105 | 313 | 32.9 | Re-entered Aug 30, 1961 (7 days) |
| Explorer 13 | 1961 Chi | NASA (GSFC) | Aug 25, 1961 | WI | Scout | 187 | 97.3 | 175 | 606 | 36.4 | Re-entered Aug 28, 1961 (3 days) |
| Discoverer 29 | 1961 Psi | USAF | Aug 30, 1961 | VAFB | Thor-Agena B | 2100 | 91 | 140 | 345 | 82.1 | Re-entered Sept 10, 1961 (11 days); capsule recovered from ocean |
| Samos 3 | None | USAF | Sept 9, 1961 | PA | Atlas-Agena B | 4200 | — | — | — | — | Failed to orbit |
| Discoverer 30 | 1961 Omega 1 | USAF | Sept 12, 1961 | VAFB | Thor-Agena B | 2100 | 92.4 | 154 | 345 | 82.6 | Re-entered Dec 11, 1961 (90 days); capsule recovered in air |
| Mercury-Atlas 4 | 1961 Alpha Alpha 1 | NASA | Sept 13, 1961 | AMR | Atlas D | 2700 | 88.6 | 100 | 159 | 32.6 | Spacecraft recovered from ocean (Sept 13, 1961) |
| Discoverer 31 | 1961 Alpha Beta | USAF | Sept 17, 1961 | VAFB | Thor-Agena B | 2100 | 91 | 152 | 255 | 82.7 | Re-entered Oct 26, 1961 (39 days); malfunction prevented capsule ejection |

AMR: Atlantic Missile Range
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VAFB: Vandenberg Air Force Base

Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Discoverer 32 | 1961 Alpha Gamma 1 | USAF | Oct 13, 1961 | VAFB | Thor-Agena B | 2100 | 90.8 | 147 | 246 | 81.7 | Re-entered Nov 13, 1961 (31 days); capsule recovered in air |
| Midas 4 | 1961 Alpha Delta | USAF | Oct 21, 1961 | PA | Atlas-Agena B | 3500 | 172/166.0 | /2175 | /2330 | /95.9 | In orbit; ejected Westford experiment package |
| Discoverer 33 | None | USAF | Oct 23, 1961 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Failed to orbit |
| Mercury-Scout 1 | None | NASA | Nov 1, 1961 | AMR | Scout | 150 | — | — | — | — | Failed to orbit |
| Discoverer 34 | 1961 Alpha Epsilon 1 | USAF | Nov 5, 1961 | VAFB | Thor-Agena B | 2100 | 97.2/90.1 | 134/129 | 637/217 | 82.7/82.5 | In orbit (silent); malfunction prevented capsule ejection |
| Discoverer 35 | 1961 Alpha Zeta 1 | USAF | Nov 15, 1961 | VAFB | Thor-Agena B | 2100 | 89.8 | 147 | 173 | 81.6 | Re-entered Dec 3, 1961 (18 days); capsule recovered in air |
| Transit 4B | 1961 Alpha Eta 1 | USN | Nov 15, 1961 | AMR | Thor-Able Star | 190 | 105.6/105.6 | 582/569 | 700/712 | 33.4/32.4 | In orbit (silent) |
| Traac | 1961 Alpha Eta 2 | | | | | 240 | 105.6/105.6 | 562/604 | 720/679 | 32.4/32.4 | In orbit (silent) |
| Ranger 2 | 1961 Alpha Theta 1 | NASA | Nov 18, 1961 | AMR | Atlas-Agena B | 675 | 88.3 | 98 | 147 | 33.3 | Re-entered Nov 18, 1961 |
| None | | USAF | Nov 22, 1961 | PA | Atlas-Agena B | Unknown | | | | | "Successfully launched," no other data released |
| Mercury-Atlas 5 | 1961 Alpha Iota 1 | NASA | Nov 29, 1961 | AMR | Atlas D | 2900 | 88.5 | 100 | 148 | 32.5 | Spacecraft recovered from ocean (Nov 29, 1961) |
| Discoverer 36 | 1961 Alpha Kappa 1 | USAF | Dec 12, 1961 | VAFB | Thor-Agena B | 2100 | 91.5 | 148 | 280 | 81.2 | Re-entered March 8, 1962 (86 days); capsule recovered from ocean |
| Oscar 1 | 1961 Alpha Kappa 2 | | | | | 10 | 91.1 | 146 | 258 | 81.2 | Re-entered Jan 31, 1962 (50 days) |
| None | | USAF | Dec 22, 1961 | PA | Atlas-Agena B | Unknown | | | | | "Successfully launched," no other data released |
| Discoverer 37 | None | USAF | Jan 13, 1962 | VAFB | Thor-Agena B | 2100 | — | — | — | — | Failed to orbit |
| Composite 1 | None | USN | Jan 24, 1962 | AMR | Thor-Able Star | 219 | — | — | — | — | Failed to orbit |
| Ranger 3 | 1962 Alpha 1 | NASA | Jan 26, 1962 | AMR | Atlas-Agena B | 727 | 406.4 days | 0.9839 AU** | 1.160 AU | 0.3988††† | Lunar probe: in solar orbit (silent) |
| Tiros 4 | 1962 Beta 1 | NASA (GSFC) | Feb 8, 1962 | AMR | Delta | 285 | 100.4/100.3 | 441/451 | 525/514 | 48.3/48.3 | In orbit (active) |
| Mercury-Atlas 6 | 1962 Gamma | NASA | Feb 20, 1962 | AMR | Atlas D | 2987 | 88.5 | 100 | 163 | 32.5 | Manned spacecraft recovered from ocean after 3 orbits (Feb 20, 1962) |
| None | | USAF | Feb 21, 1962 | VAFB | Thor-Agena B | Unknown | | | | | "Successfully launched," no other data released |

AMR: Atlantic Missile Range
PA: Point Arguello
WI: Wallops Island
VAFB: Vandenberg Air Force Base

** Astronomical Units

††† Inclination from the ecliptic

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Discoverer 38 | 1962 Epsilon 1 | USAF | Feb 27, 1962 | VAFB | Thor-Agena B | 2100 | 89.7 | 208 | 308 | 82.2 | Re-entered March 21, 1962 (22 days); capsule recovered in air |
| OSO 1 (S-16) | 1962 Zeta 1 | NASA (GSFC) | March 7, 1962 | AMR | Delta | 458 | 96.2/95.9 | 344/347 | 370/361 | 32.8/32.8 | In orbit (active) |
| None | | USAF | March 7, 1962 | PA | Atlas-Agena B | Unknown | | | | | "Successfully launched," no other data released |
| Cosmos 1 | 1962 Theta 1 | USSR | March 16, 1962 | Unknown | Unknown | Unknown | 96.4 | 135 | 609 | 49 | Re-entered May 25, 1962 (270 days) |
| Cosmos 2 | 1962 ι 1 | USSR | April 6, 1962 | Kapustin Yar | | | 102.0<br>93.8 | 131<br>124 | 960<br>456 | 49.0<br>48.9 | In orbit: unannounced payload |
| None | 1962 κ 1 | USAF | April 9, 1962 | PA | Atlas-Agena B | | 153.0<br>153.0 | 1731<br>1728 | 2116<br>2121 | 86.7<br>86.7 | In orbit: classified payload (initial orbital data as of April 10, 1962) |
| None | 1962 λ 1 | USAF | April 17, 1962 | VAFB | Thor-Agena B | | 91.5 | 98 | 333 | 73.5 | Decayed May 28, 1962: classified payload (initial orbital data as of April 30, 1962) |
| Ranger 4 | 1962 μ 1 | NASA | April 23, 1962 | AMR | Atlas-Agena B | 730 | Flight time: 64.0 hours | | | | Impacted on moon: experiments inoperative due to timer failure |
| Cosmos 3 | 1962 ν 1 | USSR | April 24, 1962 | Kapustin Yar | | | 93.8 | 142 | 447 | 49.0 | Decayed October 17, 1962: unannounced payload |
| Cosmos 4 | 1962 ξ 1 | USSR | April 26, 1962 | Tyuratam | | | 90.6 | 184 | 205 | 65.0 | Re-entered or decayed April 29, 1962: unannounced payload |
| Ariel (S-51) | 1962 ο 1 | NASA/UK (GSFC) | April 26, 1962 | AMR | Delta | 132 | 100.9<br>100.7 | 242<br>246 | 754<br>739 | 53.9<br>53.9 | In orbit: first NASA international satellite, transmitting on 136.407 mc |
| None | None | USAF | April 26, 1962 | PA | Blue Scout | | — | — | — | — | Failed to orbit: classified payload |
| None | 1962 π 1 | USAF | April 26, 1962 | PA | Atlas-Agena B | | | | | | Decayed April 28, 1962: classified payload |
| None | 1962 ρ 1 | USAF | April 28, 1962 | VAFB | Thor-Agena B | | 91.1 | 98 | 307 | 73.2 | Decayed May 26, 1962: classified payload (initial orbital data as of April 30, 1962) |
| Anna 1A | None | USN | May 10, 1962 | AMR | Thor-Able Star | 355 | — | — | — | — | Failed to orbit: second stage ignition malfunction |
| None | 1962 Σ 1 | USAF | May 15, 1962 | VAFB | Thor-Agena B | | 94.0<br>92.3 | 180<br>172 | 401<br>303 | 82.5<br>82.3 | In orbit: classified payload (initial orbital data as of May 17, 1962) |
| None | None | USAF | May 23, 1962 | PA | Blue Scout | | — | — | — | — | Failed to orbit: classified payload |
| Mercury-Atlas 7 | 1962 τ 1 | NASA | May 24, 1962 | AMR | Atlas D | 2975 | 88.3 | 100 | 167 | 32.5 | Re-entered May 24, 1962: "Aurora 7" and S. Carpenter recovered after 3 orbits |
| Cosmos 5 | 1962 υ 1 | USSR | May 28, 1962 | Kapustin Yar | | | 102.8 | 126 | 994 | 49.1 | Decayed May 2, 1963: unannounced payload |

**AMR:** Atlantic Missile Range
**PA:** Point Arguello
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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1962 Φ 1 | USAF | May 29, 1962 | VAFB | Thor-Agena B | | 89.9 | 121 | 212 | 74.1 | Decayed June 11, 1962: classified payload (initial orbital data as of May 31, 1962) |
| None | 1962 Χ 1 | USAF | June 2, 1962 | VAFB | Thor-Agena B | | 90.5 | 131 | 241 | 74.3 | Decayed June 28, 1962: classified payload (initial orbital data as of June 5, 1962) |
| Oscar 2 | 1962 Χ 2 | | | | | 10 | 90.5 | 129 | 240 | 74.3 | Decayed June 21, 1962: amateur radio satellite (initial orbital data as of June 5, 1962) |
| None | 1962 Ψ 1 | USAF | June 17, 1962 | PA | Atlas-Agena B | | | | | | Decayed June 18, 1962: classified payload |
| None | 1962 Ο 1 | USAF | June 18, 1962 | VAFB | Thor-Agena B | | 92.3<br>91.4 | 234<br>204 | 244<br>220 | 82.0<br>82.1 | In orbit: classified payload (initial orbital data as of June 19, 1962) |
| Tiros 5 | 1962 ΑΑ 1 | NASA (GSFC) | June 19, 1962 | AMR | Delta | 286 | 100.5<br>100.4 | 367<br>362 | 604<br>609 | 58.1<br>58.1 | In orbit: returned 57,857 cloud cover photos until May 4, 1963 |
| None | 1962 ΑΒ 1 | USAF | June 22, 1962 | VAFB | Thor-Agena B | | 89.0 | 130 | 150 | 75.1 | Decayed July 7, 1962: classified payload (initial orbital data as of June 30, 1962) |
| None | 1962 ΑΓ 1 | USAF | June 27, 1962 | VAFB | Thor-Agena D | | 93.6 | 131 | 398 | 76.0 | Decayed September 14, 1962: classified payload (initial orbital data as of June 30, 1962) |
| Cosmos 6 | 1962 ΑΔ 1 | USSR | June 30, 1962 | Kapustin Yar | | | 90.1 | 168 | 221 | 48.9 | Decayed August 8, 1962: unannounced payload |
| Telstar 1 | 1962 ΑΕ 1 | AT&T (GSFC-Asst'd.) | July 10, 1962 | AMR | Delta | 170 | 157.8<br>157.7 | 593<br>593 | 3503<br>3502 | 44.8<br>44.8 | In orbit: first active repeater comsat, transmitted until February 21, 1963 |
| None | 1962 ΑΖ 1 | USAF | July 18, 1962 | PA | Atlas-Agena B | | | | | | Decayed July 27, 1962: classified payload |
| None | 1962 ΑΗ 1 | USAF | July 20, 1962 | VAFB | Thor-Agena B | | 90.0 | 122 | 218 | 70.3 | Decayed August 14, 1962: classified payload (initial orbital data as of July 31, 1962) |
| Mariner 1 | None | NASA | July 22, 1962 | AMR | Atlas-Agena B | 446 | — | — | — | — | Venus probe failed: destroyed by range safety officer |
| None | 1962 ΑΘ 1 | USAF | July 28, 1962 | VAFB | Thor-Agena B | | 90.7 | 129 | 251 | 71.1 | Decayed August 24, 1962: classified payload (initial orbital data as of July 31, 1962) |
| Cosmos 7 | 1962 ΑΙ 1 | USSR | July 28, 1962 | Tyuratam | | | 90.1 | 130 | 229 | 65.0 | Re-entered or decayed August 1, 1962: unannounced payload |

AMR: Atlantic Missile Range
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Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1962 AK 1 | USAF | Aug 1, 1962 | VAFB | Thor-Agena D | | 90.2 | 121 | 227 | 82.3 | Decayed August 26, 1962: classified payload (initial orbital data as of August 14, 1962) |
| None | 1962 AΛ 1 | USAF | Aug 5, 1962 | PA | Atlas-Agena B | | | | | | Decayed August 6, 1962: classified payload |
| Vostok 3 | 1962 AM 1 | USSR | Aug 11, 1962 | Tyuratam | | "about 10,160" | 88.3 | 112 | 146 | 65.0 | Re-entered August 15, 1962: cabin and A. Nikolayev landed separately after 64 orbits |
| Vostok 4 | 1962 AN 1 | USSR | Aug 12, 1962 | Tyuratam | | "about 10,160" | 88.4 | 112 | 147 | 65.0 | Re-entered August 15, 1962: cabin and P. Popovich landed separately after 48 orbits, 6 minutes after Vostok 3 re-entry; initial orbit placed Vostok 4 within 3.1 miles of Vostok 3 |
| Cosmos 8 | 1962 AΞ 1 | USSR | Aug 18, 1962 | Kapustin Yar | | | 92.9<br>90.9 | 159<br>149 | 375<br>251 | 49.0<br>49.0 | In orbit: unannounced payload |
| None | 1962 AO 1 | USAF | Aug 23, 1962 | PA | Blue Scout | | 99.6<br>99.6 | 388<br>390 | 526<br>526 | 98.6<br>98.6 | In orbit: classified payload (initial orbital data as of August 31, 1962) |
| None | 1962 AΠ 1 | USSR | Aug 25, 1962 | | | | 99.6 | 390 | 526 | 98.6 | Decayed August 28, 1962: probable Venus probe failure |
| Mariner 2 | 1962 AP 1 | NASA | Aug 26, 1962 | AMR | Atlas-Agena B | 447 | 348 days | .7046 AU** | 1.229 AU | 1.66††† | In solar orbit: Venus probe, passed within 21,594 miles of planet, reported surface temperature of 800°F, returned data out to 54.3M miles |
| None | 1962 AΣ 1 | USAF | Aug 28, 1962 | VAFB | Thor-Agena D | | 90.4 | 114 | 250 | 65.2 | Decayed September 10, 1962: classified payload (initial orbital data as of August 31, 1962) |
| None | 1962 AT 1 | USSR | Sept 1, 1962 | | | | | | | | Decayed September 6, 1962: probable Venus probe failure |
| None | 1962 AY 1 | USAF | Sept 1, 1962 | VAFB | Thor-Agena B | | 94.4<br>93.5 | 189<br>176 | 418<br>377 | 82.8<br>82.8 | In orbit: classified payload (initial orbital data as of September 15, 1962) |
| None | 1962 AΦ 1 | USSR | Sept 12, 1962 | | | | | | | | Results unknown: probable Venus probe failure |
| None TRS 1 | 1962 AX 1 | USAF | Sept 17, 1962 | VAFB | Thor-Agena B | /1.5 | 92.8 | 124 | 383 | 81.9 | Decayed November 19, 1962: classified payload, failed to eject TRS pickaback which returned solar cell damage data (initial orbital data as of September 30, 1962) |

AMR: Atlantic Missile Range
PA: Point Arguello
WI: Wallops Island
VAFB: Vandenberg Air Force Base

** Astronomical Units

††† Inclination from the ecliptic

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Tiros 6 | 1962 AΨ 1 | NASA (GSFC) | Sept 18, 1962 | AMR | Delta | 281 | 98.7<br>98.7 | 423<br>423 | 444<br>445 | 58.2<br>58.3 | In orbit: wide angle camera operating, transmissions on 136.233, 136.922 mc |
| Cosmos 9 | 1962 AΩ 1 | USSR | Sept 27, 1962 | Tyuratam | | | 90.0 | 187 | 220 | 65.0 | Re-entered or decayed October 1, 1962: unannounced payload |
| Alouette (S-27) | 1962 BA 1 | Canada (GSFC-Asst'd.) | Sept 28, 1962 | VAFB | Thor-Agena B | 320 | 105.4<br>105.5 | 620<br>624 | 638<br>639 | 80.5<br>80.5 | In orbit: ionosphere sounding satellite, transmitting on 136.593, 136.979 mc |
| None | 1962 BB 1 | USAF | Sept 29, 1962 | VAFB | Thor-Agena D | | 90.3 | 119 | 241 | 65.4 | Decayed October 14, 1962: classified payload (initial orbital data as of September 30, 1962) |
| Explorer 14 (S-3a) | 1962 BΓ 1 | NASA (GSFC) | Oct 2, 1962 | AMR | Delta | 89 | 2184<br>2185 | 174<br>778 | 61,190<br>60,606 | 32.9<br>37.4 | In orbit: energetic particles satellite, transmitting on 136.440 mc |
| Mercury-Atlas 8 | 1962 BΔ 1 | NASA | Oct 3, 1962 | AMR | Atlas D | 3030 | 89.0 | 100 | 176 | 32.5 | Re-entered October 3, 1962: "Sigma 7" with W. Schirra recovered after 6 orbits |
| None | 1962 BE 1 | USAF | Oct 9, 1962 | VAFB | Thor-Agena B | | 90.9 | 103 | 291 | 81.5 | Decayed November 16, 1962: classified payload (initial orbital data as of October 10, 1962) |
| Cosmos 10 | 1962 BZ 1 | USSR | Oct 17, 1962 | Tyuratam | | | 90.2 | 130 | 236 | 65.0 | Re-entered or decayed October 21, 1962: unannounced payload |
| Ranger 5 | 1962 BH 1 | NASA | Oct 19, 1962 | AMR | Atlas-Agena B | 755 | 370 days | .9498 AU** | 1.0681 AU | .4442††† | In solar orbit: lunar probe, missed moon by 450 miles |
| Cosmos 11 | 1962 BΘ 1 | USSR | Oct 20, 1962 | Kapustin Yar | | | 96.1<br>94.6 | 152<br>150 | 572<br>475 | 49.0<br>49.0 | In orbit: unannounced payload |
| None | 1962 BI 1 | USSR | Oct 24, 1962 | | | | | | | | Results unknown: probable Mars probe failure |
| None | 1962 BK 1 | USAF | Oct 26, 1962 | VAFB | Thor-Agena D | | 147.8<br>144.0 | 120<br>126 | 3452<br>3258 | 71.4<br>71.4 | In orbit: "Starad" payload returned radiation data until January 18, 1963 |
| Explorer 15 (S-3b) | 1962 BΛ 1 | NASA (GSFC) | Oct 27, 1962 | AMR | Delta | 98 | 312.0<br>314.7 | 194<br>197 | 10,760<br>10,938 | 18.0<br>18.0 | In orbit: excessive spin rate degraded radiation data, transmitted until February, 1963 |
| Anna 1B | 1962 BM 1 | USN | Oct 31, 1962 | AMR | Thor-Able Star | 350 | 107.8<br>107.8 | 670<br>670 | 728<br>734 | 50.1<br>50.1 | In orbit: flash tubes operated until January 8, 1963, transmitting on 162,324 mc |
| Mars 1 | 1962 BN 3 | USSR | Nov 1, 1962 | | | 1965 | In Heliocentric Orbit | | | | In solar orbit: Mars probe, transmissions ceased after 66M miles |
| None | 1962 BΞ 1 | USSR | Nov 4, 1962 | | | | | | | | Results unknown: probable Mars probe failure |

AMR: Atlantic Missile Range
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** Astronomical Units

††† Inclination from the ecliptic

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1962 BO 1 | USAF | Nov 5, 1962 | VAFB | Thor-Agena B | | 90.7 | 130 | 250 | 75.0 | Decayed December 3, 1962: classified payload (initial orbital data as of November 7, 1962) |
| None | 1962 Bπ 1 | USAF | Nov 11, 1962 | VAFB | Thor-Agena B | | | | | | Decayed November 12, 1962: classified payload |
| None | 1962 BP 1 | USAF | Nov 24, 1962 | VAFB | Thor-Agena B | | 89.8 | 129 | 202 | 65.2 | Decayed December 13, 1962: classified payload (initial orbital data as of November 30, 1962) |
| None | 1962 BΣ 1 | USAF | Dec 4, 1962 | VAFB | Thor-Agena D | | 89.2 | 119 | 175 | 65.0 | Decayed December 8, 1962: classified payload (initial orbital data as of December 6, 1962) |
| None | 1962 BT 1 | USAF | Dec 12, 1962 | VAFB | Thor-Agena D | | 116.0<br>114.9 | 153<br>135 | 1724<br>1650 | 70.4<br>70.4 | In orbit: classified payload (initial orbital data as of December 15, 1962) |
| Injun 3 | 1962 BT 2 | | | | | 114 | 116.3<br>115.4 | 153<br>144 | 1729<br>1686 | 70.3<br>70.4 | In orbit: transmitting radiation data on 136.860 mc |
| None | 1962 BT 3 | | | | | | 115.6<br>100.4 | 139<br>148 | 1700<br>820 | 70.3<br>70.3 | In orbit: classified pickaback |
| None | 1962 BT 4 | | | | | | 116.2<br>113.7 | 145<br>126 | 1728<br>1609 | 70.4<br>70.3 | In orbit: classified pickaback |
| None | 1962 BT 5 | | | | | | 116.0<br>114.6 | 146<br>136 | 1718<br>1647 | 70.3<br>70.4 | In orbit: classified pickaback |
| Relay 1 | 1962 BY 1 | NASA (GSFC) | Dec 13, 1962 | AMR | Delta | 172 | 185.9<br>185.0 | 819<br>820 | 4612<br>4625 | 47.5<br>47.5 | In orbit: active repeater comsat, transmitting on 136.140 mc |
| None | 1962 BΦ 1 | USAF | Dec 14, 1962 | VAFB | Thor-Agena D | | 90.5 | 126 | 241 | 70.0 | Decayed January 8, 1963: classified payload (initial orbital data as of December 15, 1962) |
| Explorer 16 | 1962 BX 1 | NASA (LRC) | Dec 16, 1962 | WI | Scout | 222 | 104.4<br>104.3 | 466<br>462 | 733<br>737 | 52.0<br>52.0 | In orbit: micrometeorite satellite, transmitting on 136.200, 136.860 mc |
| None | None | USAF | Dec 17, 1962 | PA | Atlas-Agena B | | — | — | — | — | Failed to orbit: classified payload |
| Transit 5A | 1962 BΨ 1 | USN | Dec 18, 1962 | PA | Blue Scout | 135 | 99.2<br>99.2 | 432<br>428 | 455<br>461 | 90.7<br>90.6 | In orbit: power supply malfunction after 1 day |
| Cosmos 12 | 1962 BΩ 1 | USSR | Dec 22, 1962 | Tyuratam | | | 90.5 | 131 | 252 | 65.0 | Re-entered or decayed December 30, 1962: unannounced payload |
| None | 1963 1A | USSR | Jan 4, 1963 | | | | | | | | Results unknown: probable lunar probe failure |
| None | 1963 2A | USAF | Jan 7, 1963 | VAFB | Thor-Agena D | | 90.5 | 131 | 245 | 82.0 | Decayed January 24, 1963: classified payload (initial orbital data as of January 15, 1963) |

AMR: Atlantic Missile Range
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Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# International Log of Space Launches◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1963 3A | USAF | Jan 16, 1963 | VAFB | Thor-Agena D | | 94.7<br>94.6 | 298<br>286 | 322<br>334 | 82.0<br>81.9 | In orbit: classified payload (initial orbital data as of January 31, 1963) |
| Syncom 1 | 1963 4A | NASA (GSFC) | Feb 13, 1963 | AMR | Delta | 86 | 1426.5<br>1426.5 | 21,268<br>21,242 | 22,974<br>23,004 | 33.5<br>33.5 | In orbit: communication lost at injection into synchronous orbit |
| None | 1963 5A | USAF | Feb 19, 1963 | PA | Blue Scout | | 97.8<br>97.8 | 305<br>315 | 498<br>449 | 100.5<br>100.5 | In orbit: classified payload (initial orbital data as of February 28, 1963) |
| None | None | USAF | Feb 28, 1963 | VAFB | Thor-Agena D | | — | — | — | — | Failed to orbit: classified payload, first use of thrust-augmented Thor |
| None | None | USAF | March 18, 1963 | VAFB | Thor-Agena D | | — | — | — | — | Failed to orbit: classified payload, employed thrust-augmented Thor |
| Cosmos 13 | 1963 6A | USSR | March 20, 1963 | Tyuratam | | | 89.8 | 127 | 209 | 65.0 | Re-entered or decayed March 29, 1963: unannounced payload |
| None | 1963 7A | USAF | April 1, 1963 | VAFB | Thor-Agena D | | | | | | Decayed April 26, 1963: classified payload |
| Lunik 4 | 1963 8B | USSR | April 2, 1963 | | | 3135 | | 55,800 | 434,000 | | In orbit: lunar probe, missed moon by 5281 miles, will enter solar orbit |
| Explorer 17 (S-6) | 1963 9A | NASA (GSFC) | April 2, 1963 | AMR | Delta | 405 | 96.4<br>96.3 | 158<br>153 | 570<br>570 | 57.6<br>57.6 | In orbit: atmospheric structure satellite, transmitting on 136.32, 136.56 mc |
| None | None | USAF | April 5, 1963 | PA | Blue Scout | | — | — | — | — | Failed to orbit: classified payload |
| Cosmos 14 | 1963 10A | USSR | April 13, 1963 | Kapustin Yar | | | 92.1<br>91.7 | 165<br>160 | 318<br>291 | 48.6<br>48.9 | In orbit: unannounced payload |
| Cosmos 15 | 1963 11A | USSR | April 22, 1963 | Tyuratam | | | 89.8 | 107 | 231 | 65.0 | Re-entered or decayed April 27, 1963: unannounced payload |
| None | None | USAF | April 26, 1963 | PA | Blue Scout | | — | — | — | — | Failed to orbit: classified payload |
| None | None | USAF | April 26, 1963 | VAFB | Thor-Agena D | | — | — | — | — | Failed to orbit: classified payload |
| Cosmos 16 | 1963 12A | USSR | April 28, 1963 | Tyuratam | | | 90.4 | 129 | 249 | 65.0 | Re-entered or decayed May 8, 1963: unannounced payload |
| Telstar 2 | 1963 13A | AT&T (GSFC-Asst'd.) | May 7, 1963 | AMR | Delta | 175 | 225.0 | 604 | 6713 | 42.7 | In orbit: active repeater comsat, transmitting on 136.050 mc |
| None | 1963 14A | USAF | May 9, 1963 | PA | Atlas-Agena B | | 167.0 | 2241 | 2289 | 87.4 | In orbit: classified payload (initial orbital data as of May 15, 1963) |
| Mercury-Atlas 9 | 1963 15A | NASA | May 15, 1963 | AMR | Atlas D | 3000 | 88.5 | 100 | 166 | 32.5 | Re-entered May 16, 1963: "Faith 7" with G. Cooper recovered after 22 orbits |

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Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1963 16A | USAF | May 18, 1963 | VAFB | Thor-Agena D | | | | | | Decayed May 27, 1963: classified payload |
| Cosmos 17 | 1963 17A | USSR | May 22, 1963 | Kapustin Yar | | | 94.8<br>94.5 | 162<br>155 | 490<br>477 | 49.0<br>48.9 | In orbit: unannounced payload |
| Cosmos 18 | 1963 18A | USSR | May 24, 1963 | Tyuratam | | | 89.4 | 130 | 187 | 65.0 | Re-entered or decayed June 2, 1963: unannounced payload |
| None | None | USAF | June 12, 1963 | PA | Atlas-Agena B | | — | — | — | — | Failed to orbit: classified payload |
| None | 1963 19A | USAF | June 12, 1963 | VAFB | Thor-Agena D | | 90.7 | 120 | 262 | 81.9 | Decayed July 12, 1963: classified payload (initial orbital data as of June 15, 1963) |
| Vostok 5 | 1963 20A | USSR | June 14, 1963 | Tyuratam | | "about 10,160" | 88.3 | 109 | 138 | 65.0 | Re-entered June 19, 1963: cabin, V. Bykovsky landed after 82 orbits |
| None | 1963 21A | USAF/USN | June 15, 1963 | VAFB | Thor-Agena D | | 94.5 | 110 | 501 | 69.9 | Decayed August 7, 1963: classified payload (initial orbital data as of June 30, 1963) |
| Lofti 2A | 1963 21B | | | | | | 93.7 | 114 | 449 | 69.9 | Decayed July 18, 1963: VLF experiment payload |
| Greb 4 | 1963 21C | | | | | | 94.1 | 110 | 480 | 69.8 | Decayed August 1, 1963: solar radiation payload |
| Radose | 1963 21D | | | | | | 94.1 | 103 | 487 | 68.9 | Decayed July 30, 1963: classified payload |
| None | 1963 21E | | | | | | 94.0 | 110 | 472 | 69.9 | Decayed July 27, 1963: classified payload |
| None | 1963 21F | | | | | | 91.7 | 102 | 341 | 69.8 | Decayed July 5, 1963: classified payload |
| None | 1963 22A | USAF | June 15, 1963 | PA | Blue Scout | | 99.8<br>99.8 | 450<br>459 | 475<br>469 | 90.0<br>90.0 | In orbit: classified payload (initial orbital data as of June 30, 1963) |
| Vostok 6 | 1963 23A | USSR | June 16, 1963 | Tyuratam | | "about 10,160" | 88.4 | 114 | 145 | 65.0 | Re-entered June 19, 1963: cabin and V. Tereshkova landed separately after 49 orbits, 3 hours before Vostok 5 landing |

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Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Tiros 7 | 1963 24A | NASA (GSFC) | June 19, 1963 | AMR | Delta | 297 | 97.4<br>97.4 | 385<br>382 | 401<br>409 | 58.2<br>58.2 | In orbit: wide angle cameras, IR experiments operating, transmissions on 136.232, 136.922 mc |
| None | 1963 25A | USAF | June 26, 1963 | VAFB | Thor-Agena D | | 90.5 | 124 | 247 | 81.6 | Decayed July 26, 1963: classified payload (initial orbital data as of June 30, 1963) |
| Hitch-hiker 1 | 1963 25B | | | | | 176 | 132.6<br>132.5 | 201<br>214 | 2571<br>2558 | 82.1<br>82.1 | In orbit: pickaback to measure artificial radiation decay |
| Geophysical Research Satellite | 1963 26A | USAF | June 28, 1963 | WI | Scout | | 102.1<br>102.1 | 255<br>262 | 815<br>807 | 49.7<br>49.7 | In orbit: no details released (initial orbital data as of June 30, 1963) |
| None | 1963 27A | USAF | June 29, 1963 | VAFB | Thor-Agena B | | 94.8<br>94.8 | 308<br>303 | 319<br>327 | 82.3<br>82.3 | In orbit: classified payload (initial orbital data as of July 15, 1963) |
| None | 1963 28A | USAF | July 12, 1963 | PA | Atlas-Agena D | | 88.3 | 114 | 116 | 95.4 | Decayed July 18, 1963: 100th Agena launched to date; classified payload (initial orbital data as of July 15, 1963) |
| None | 1963 29A | USAF | July 18, 1963 | VAFB | Thor-Agena D | | 89.9 | 120 | 209 | 82.9 | Decayed August 13, 1963: classified payload (initial orbital data as of July 31, 1963) |
| None | 1963 30A | USAF | July 19, 1963 | VAFB | Atlas-Agena B | | 167.9<br>167.9 | 2279<br>2280 | 2321<br>2320 | 88.4<br>88.4 | In orbit: classified payload (initial orbital data as of July 31, 1963) |
| Syncom 2 | 1963 31A | NASA (GSFC) | July 26, 1963 | AMR | Delta | 86 | 1408 | 22,132 | 22,823 | 30 | In orbit: active-repeater comsat, moved to position over Brazil, early communication tests successful |
| None | 1963 32A | USAF | July 30, 1963 | VAFB | Thor-Agena D | | 90.6 | 94 | 283 | 74.9 | Decayed August 11, 1963: classified payload (initial orbital data as of July 31, 1963) |
| Cosmos 19 | 1963 33A | USSR | Aug 6, 1963 | Kapustin Yar | | | 92.2<br>92.1 | 168<br>163 | 322<br>311 | 49.0<br>49.0 | In orbit: unannounced payload |

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Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆(CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1963 34A | USAF | Aug 24, 1963 | VAFB | Thor-Agena D | | 90.5 | 108 | 261 | 75.0 | Decayed September 12, 1963: classified payload, employed thrust-augmented Thor (initial orbital data as of August 31, 1963) |
| None<br>None | 1963 35A<br>1963 35B | USAF | Aug 29, 1963 | VAFB | Thor-Agena D | | 90.8<br>88.3 | 176<br>115 | 211<br>116 | 81.8<br>81.9 | Decayed November 7, 1963: classified payload (initial orbital data as of August 31, 1963)<br>Decayed October 28, 1963: classified payload (initial orbital data as of September 30, 1963) |
| None | 1963 36A | USAF | Sept 6, 1963 | PA | Atlas-Agena D | | | | | | Decayed September 13, 1963: classified payload |
| None | 1963 37A | USAF | Sept 23, 1963 | VAFB | Thor-Agena D | | 90.5 | 109 | 257 | 74.9 | Decayed October 12, 1963: classified payload, employed thrust-augmented Thor (initial orbital data as of September 30, 1963) |
| None | None | USAF | Sept 27, 1963 | PA | Scout | | — | — | — | — | Failed to orbit: classified payload |
| None | 1963 38A | USAF/USN | Sept 28, 1963 | VAFB | Thor-Able Star | | 107.1<br>107.1 | 669<br>662 | 687<br>695 | 89.9<br>89.9 | In orbit: classified payload included 27-pound SNAP-9A nuclear power supply (initial orbital data as of September 30, 1963) |
| None<br>None | 1963 39A<br>1963 39B | USAF | Oct 16, 1963 | AMR | Atlas-Agena D | | | | | | In orbit: classified payload<br>In orbit: classified payload |
| Cosmos 20 | 1963 40B | USSR | Oct 18, 1963 | Tyuratum | | | | 123 | 186 | 65.0 | Re-entered or decayed October 30, 1963: unannounced payload |
| None | 1963 41A | USAF | Oct 25, 1963 | PA | Atlas-Agena D | | | | | | Decayed October 29, 1963: classified payload |
| None | 1963 42A | USAF | Oct 29, 1963 | VAFB | Thor-Agena D | | 90.9<br>90.7 | 173<br>170 | 218<br>210 | 89.9<br>89.9 | In orbit: classified payload, employed thrust-augmented Thor (initial orbital data as of October 31, 1963) |

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# International Log of Space Launches◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Polyot 1 | 1963 43A | USSR | Nov 1, 1963 | | | | 102.4 | 211<br>214 | 329<br>870 | 58.9 | In orbit: first Soviet spacecraft with extensive maneuver capability |
| None | None | USAF | Nov 9, 1963 | WTR | Thor-Agena D | | — | — | — | — | Failed to orbit: classified payload |
| Cosmos 21 | 1963 44A | USSR | Nov 11, 1963 | Tyuratam | | | 88.5 | 121 | 142 | 64.9 | Re-entered or decayed November 14, 1963: unannounced payload |
| Cosmos 22 | 1963 45A | USSR | Nov 16, 1963 | Tyuratam | | | 90.3 | 127 | 245 | 64.9 | Re-entered or decayed November 22, 1963: unannounced payload |
| Explorer 18 | 1963 46A | NASA (GSFC) | Nov 26, 1963 | ETR | Delta | 138 | 96.3 hrs<br>93.3 hrs | 119<br>744 | 122,522<br>121,510 | 33.3<br>33.3 | In orbit: IMP A, apogee lower than planned, transmitting on 136.110 mc, discovered high-energy radiation region beyond Van Allen belt |
| Atlas-Centaur 2 | 1963 47A | NASA | Nov 27, 1963 | ETR | Atlas-Centaur | 10,700 | 107.7<br>107.9 | 303<br>297 | 1093<br>1107 | 30.4<br>30.4 | In orbit: AC-2 second stage, carried no experiments, not considered a spacecraft |
| None | 1963 48A | USAF | Nov 27, 1963 | PA | Thor-Agena D | | 90.1 | 109 | 236 | 70.0 | Decayed December 15, 1963: classified payload |
| None | 1963 49B | USAF/USN | Dec 5, 1963 | WTR | Thor-Able Star | | 107.2<br>107.1 | 665<br>656 | 690<br>700 | 90.0<br>90.0 | In orbit: classified payload included SNAP-9A nuclear power supply, transmitting on 150, 400 mc |
| None | 1963 49C | | | | | | 107.2<br>107.0 | 666<br>656 | 689<br>698 | 90.0<br>90.0 | In orbit: classified payload, transmitting on 54, 162, 324, 688 mc |
| Cosmos 23 | 1963 50A | USSR | Dec 13, 1963 | Kapustin Yar | | | 92.9<br>90.8 | 149<br>137 | 381<br>255 | 49.0<br>49.0 | In orbit: unannounced payload |
| None | 1963 51A | USAF | Dec 18, 1963 | PA | Atlas-Agena D | | | | | | Decayed December 20, 1963: classified payload |
| Cosmos 24 | 1963 52A | USSR | Dec 19, 1963 | Tyuratam | | | 90.5 | 131 | 254 | 65.0 | Re-entered or decayed December 24, 1963: unannounced payload |

PA: Point Arguello
ETR: Eastern Test Range
WI: Wallops Island
WTR: Western Test Range

Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆(CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Explorer 19 | 1963 53A | NASA | Dec 19, 1963 | PA | Scout | 15 | 115.9<br>115.8 | 366<br>368 | 1487<br>1484 | 78.6<br>78.6 | In orbit: 12-foot balloon identical to Explorer 9, for atmospheric density studies |
| None | None | USAF | Dec 20, 1963 | WTR | ³TAT-Agena D | | — | — | — | — | Failed to orbit: classified payload |
| Tiros 8 | 1963 54A | NASA (GSFC) | Dec 21, 1963 | ETR | Delta | 265 | 99.3<br>99.3 | 430<br>435 | 473<br>469 | 58.5<br>58.5 | In orbit: first Tiros to carry APT system, transmitting on 136.233, 136.924 mc |
| None<br>None<br>None | 1963 55A<br>1963 55B<br>1963 55C | USAF | Dec 21, 1963 | WTR | Thor-Agena D | | 89.3<br>91.7<br>91.5 | 107<br>196<br>195 | 189<br>245<br>236 | 64.9<br>64.5<br>64.5 | Decayed January 9, 1964: classified payload<br>In orbit: classified payload<br>Status unknown: classified payload |
| None<br>GGSE<br>EGRS<br>Greb 5<br>None | 1964 1A<br>1964 1B<br>1964 1C<br>1964 1D<br>1964 1E | USAF/USN | Jan 11, 1964 | WTR | TAT-Agena D | 100 | 103.5<br>103.4<br>103.5<br>103.4<br>103.5<br>103.4<br>103.5<br>103.5<br>103.5<br>103.5 | 563<br>569<br>560<br>567<br>563<br>565<br>563<br>567<br>555<br>569 | 578<br>577<br>585<br>579<br>578<br>580<br>578<br>580<br>591<br>578 | 69.9<br>69.9<br>70.0<br>69.9<br>69.9<br>69.9<br>69.9<br>69.9<br>69.9<br>69.9 | In orbit: classified payload (initial orbital data as of January 15, 1964)<br>In orbit: gravity gradient stabilization experiment<br>In orbit: classified payload, transmitting on 136.803 mc<br>In orbit: solar radiation satellite transmitting on 136.886 mc<br>In orbit: classified payload |
| None<br>None | 1964 2B<br>1964 2C | USAF | Jan 19, 1964 | WTR | Thor-Agena D | | 101.3<br>101.3<br>101.3<br>101.3 | 500<br>503<br>501<br>503 | 518<br>518<br>514<br>518 | 99.0<br>99.1<br>99.1<br>99.1 | In orbit: classified payload (initial orbital data as of January 31, 1964)<br>In orbit: classified payload |
| Relay 2 | 1964 3A | NASA (GSFC) | Jan 21, 1964 | ETR | Delta | 172 | 194.7<br>194.7 | 1298<br>1295 | 4606<br>4607 | 46.0<br>46.3 | In orbit: active-repeater comsat, transmitting on 136.142, 136.620 mc |

¹Current orbital data as of October 15, 1964
²Local time at launch site
³Thrust Augmented Thor

PA: Point Arguello
ETR: Eastern Test Range [illegible]
WTR: Western Test Range

Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆(CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Echo 2 | 1964 4A | NASA (GSFC) | Jan 25, 1964 | WTR | Thor-Agena B | 547 | 108.8<br>108.6 | 642<br>698 | 816<br>749 | 81.5<br>81.5 | In orbit: passive reflector comsat, first cooperative program with USSR, beacon transmitting on 136.020, 136.170 mc |
| Saturn SA-5 | 1964 5A | NASA | Jan 29, 1964 | ETR | Saturn I | 37,700 | 94.8<br>93.9 | 164<br>158 | 471<br>418 | 31.5<br>31.5 | In orbit: Saturn I second stage (S-IV), carried no instruments, not considered a spacecraft |
| Elektron 1 | 1964 6A | USSR | Jan 30, 1964 | | | | 169<br>169.3 | 252<br>250 | 4412<br>4422 | 61<br>60.9 | In orbit: scientific satellite to study inner Van Allen radiation belt, first dual Soviet launch |
| Elektron 2 | 1964 6B | | | | | | 1360<br>1356.4 | 286<br>411 | 42,377<br>42,105 | 61<br>59.4 | In orbit: intended to provide data on outer radiation belt, configuration differed from Elektron 1 |
| Ranger 6 | 1964 7A | NASA | Jan 30, 1964 | ETR | Atlas-Agena B | 804 | Flight time: 65.6 hours | | | | Impacted on moon: closeup photographic experiment failed to provide data |
| None | 1964 8A | USAF | Feb 15, 1964 | WTR | TAT-Agena D | | 90.9 | 119 | 278 | 75.1 | Decayed March 9, 1964: classified payload |
| None | 1964 9A | USAF | Feb 25, 1964 | WTR | Atlas-Agena D | | 88.2 | 107 | 118 | 95.7 | Decayed March 1, 1964: classified payload (initial orbital data as of February 26, 1964) |
| Cosmos 25 | 1964 10A | USSR | Feb 27, 1964 | Kapustin Yar | | | 92.3<br>90.4 | 169<br>150 | 327<br>207 | 49<br>49.1 | In orbit: unannounced payload |
| None | 1964 11A | USAF | Feb 27, 1964 | WTR | TAT-Agena D | | 94.6<br>94.6 | 302<br>307 | 319<br>317 | 82.1<br>82.1 | In orbit: classified payload |
| None | 1964 12A | USAF | Mar 11, 1964 | WTR | Atlas-Agena D | | 89.8 | 89 | 240 | 95.8 | Decayed March 16, 1964: classified payload (initial orbital data as of March 12, 1964) |

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Cosmos 26 | 1964 13A | USSR | Mar 18, 1964 | Kapustin Yar | | | 91.1 | 168 | 250 | 49 | Decayed September 28, 1964: unannounced payload |
| Beacon Explorer A | None | NASA (GSFC) | Mar 19, 1964 | ETR | Delta | 120 | — | — | — | — | Failed to orbit: insufficient third stage thrust |
| None | None | USAF | Mar 24, 1964 | WTR | TAT-Agena D | | — | — | — | — | Failed to orbit: classified payload |
| Cosmos 27 | 1964 14A | USSR | Mar 27, 1964 | Tyuratam | | | 88.4 | 119 | 147 | 64.8 | Re-entered or decayed March 28, 1964: unannounced payload |
| Ariel 2 | 1964 15A | NASA/UK (GSFC) | Mar 27, 1964 | WI | Scout | 150 | 101.3<br>100.9 | 180<br>173 | 843<br>818 | 51.6<br>51.7 | In orbit: returning data from British galactic noise, ozone and micrometeoroid experiments, transmitting on 136.558 mc |
| Zond 1 | 1964 16D | USSR | Apr 2, 1964 | | | | Heliocentric Orbit | | | | In solar orbit: only the third announced Soviet probe in long, unsuccessful interplanetary program |
| Cosmos 28 | 1964 17A | USSR | Apr 4, 1964 | Tyuratam | | | 90.4 | 130 | 245 | 65 | Re-entered or decayed April 12, 1964: unannounced payload |
| Gemini-Titan 1 | 1964 18A | NASA | Apr 8, 1964 | ETR | Titan II | 11,400 | 89.2 | 100 | 204 | 32.6 | Decayed April 12, 1964: unmanned boilerplate Gemini, plus second stage |
| Polyot 2 | 1964 19B | USSR | Apr 12, 1964 | | | | 92.5<br>92.1 | 193<br>187 | 311<br>285 | 58.1<br>58.1 | In orbit: reported to have completed series of maneuver tests during first day in orbit |
| None | None | USAF/USN | Apr 21, 1964 | WTR | Thor-Able Star | | — | — | — | — | Failed to orbit: classified payload |
| None | 1964 20A | USAF | Apr 23, 1964 | WTR | Atlas-Agena D | | 89.4 | 93 | 209 | 103.6 | Decayed April 28, 1964: classified payload (initial orbital data as of April 25, 1964) |

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Cosmos 29 | 1964 21A | USSR | Apr 25, 1964 | Tyuratam | | | 89.5 | 127 | 192 | 65.1 | Re-entered or decayed May 2, 1964: unannounced payload |
| None | 1964 22A | USAF | Apr 27, 1964 | WTR | TAT-Agena D | | 90.8 | 109 | 277 | 80.0 | Decayed May 26, 1964: classified payload (initial orbital data as of April 30, 1964) |
| Cosmos 30 | 1964 23A | USSR | May 18, 1964 | Tyuratam | | | 90.2 | 128 | 238 | 64.9 | Re-Entered or decayed May 26, 1964: Unannounced payload |
| None | 1964 24A | USAF | May 19, 1964 | WTR | Atlas-Agena D | | 101.1 | 88 | 236 | 89.7 | Decayed May 22, 1964: classified payload (initial orbital data as of May 26, 1964) |
| Saturn SA-6 | 1964 25A | NASA | May 28, 1964 | ETR | Saturn I | 37,300 | 88.5 | 124 | 140 | 31.8 | Decayed June 1, 1964: unmanned Apollo boilerplate command and service modules orbited attached to S-IV second stage |
| None | 1964 26A | USAF | June 3, 1964 | WTR | Scout | | 103.1<br>103.1 | 531<br>531 | 594<br>595 | 90.4<br>90.5 | In orbit: classified payload (initial orbital data as of June 5, 1964) |
| None | 1964 27A | USAF | June 4, 1964 | WTR | TAT-Agena D | | 90.2 | 93 | 267 | 80.0 | Decayed June 18, 1964: classified payload (initial orbital data as of June 7, 1964) |
| Cosmos 31 | 1964 28A | USSR | June 6, 1964 | Kapustin Yar | | | 91.6<br>89.1 | 142<br>112 | 316<br>152 | 49<br>49.0 | In orbit: unannounced payload |
| Cosmos 32 | 1964 29A | USSR | June 10, 1964 | | | | 89.8 | 130 | 207 | 51.3 | Re-entered or decayed June 18, 1964: unannounced payload, new inclination for Cosmos program |
| None | 1964 30A | USAF | June 13, 1964 | WTR | TAT-Agena D | | 91.7<br>91.4 | 219<br>213 | 225<br>216 | 115.0<br>115.0 | In orbit: classified payload (initial orbital data as of June 15, 1964) |

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL/CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None<br>None | 1964 31A<br>1964 31B | USAF | June 17, 1964 | WTR | Thor-Agena D | | 101.6<br>101.6<br>101.6<br>101.6 | 514<br>516<br>515<br>516 | 523<br>521<br>523<br>521 | 99.8<br>99.8<br>99.8<br>99.8 | In orbit: classified payload (initial orbital data as of June 18, 1964)<br>In orbit: classified payload |
| None | 1964 32A | USAF | June 19, 1964 | WTR | TAT-Agena D | | 91.0 | 109 | 287 | 85.0 | Decayed August 16, 1964: classified payload (initial orbital data as of June 30, 1964) |
| Cosmos 33 | 1964 33A | USSR | June 23, 1964 | Tyuratam | | | 89.4 | 130 | 182 | 65 | Re-entered or decayed July 1, 1964: unannounced payload |
| None | None | USAF | June 25, 1964 | WTR | Scout | | — | — | — | — | Failed to orbit: classified payload |
| Cosmos 34 | 1964 34A | USSR | July 1, 1964 | Tyuratam | | | 90 | 127 | 223 | 65.0 | Re-entered or decayed July 9, 1964: unannounced payload |
| None | 1964 35A | USAF | July 2, 1964 | WTR | TAT-Agena D | | 94.9<br>94.9 | 311<br>310 | 329<br>328 | 82.1<br>82.1 | In orbit: classified payload (initial orbital data as of August 3, 1964) |
| None<br>None | 1964 36A<br>1964 36B | USAF | July 6, 1964 | WTR | Atlas-Agena D | | 91.4<br>90.9 | 184<br>179 | 244<br>216 | 93.0<br>93.0 | Decayed July 8, 1964: classified payload<br>In orbit: classified payload (initial orbital data as of July 15, 1964) |
| None | 1964 37A | USAF | July 10, 1964 | WTR | TAT-Agena D | | 91.0 | 112 | 286 | 85.0 | Decayed August 6, 1964: classified payload |
| Elektron 3<br>Elektron 4 | 1964 38A<br>1964 38B | USSR | July 11, 1964 | | | | 168.2<br>1313.9 | 251<br>250<br>285<br>290 | 4365<br>4366<br>41,076<br>41,168 | 61<br>60.8<br>61<br>60.3 | In orbit: second Elektron, dual launch, research satellite to monitor radiation in inner Van Allen belt<br>In orbit: intended to make simultaneous radiation measurements in outer belt and magnetosphere |
| Cosmos 35 | 1964 39A | USSR | July 15, 1964 | | | | 89.2 | 135 | 166 | 51.3 | Re-entered or decayed July 23, 1964: unannounced payload |

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Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| NDS 3 | 1964 40A | USAF | July 17, 1964 | ETR | Atlas-Agena D | 318 | 100.3 hrs<br>100.4 hrs | 63,369<br>63,446 | 65,024<br>64,877 | 39.5<br>39.4 | In orbit: experimental nuclear detection satellite to test satellite-borne sensor system |
| NDS 4 | 1964 40B | | | | | 318 | 100.1 hrs<br>100.0 hrs | 58,766<br>58,642 | 69,482<br>69,401 | 40.9<br>40.7 | In orbit: icosahedron identical to NDS 3, lags NDS 3 by 140 degrees |
| TRS 6 | 1964 40C | | | | | 4.5 | 39.2 hrs<br>39.4 hrs | 120<br>135 | 64,886<br>65,036 | 36.7<br>36.7 | In orbit: tetrahedral research satellite intended to return radiation data |
| Ranger 7 | 1964 41A | NASA | July 28, 1964 | ETR | Atlas-Agena D | 806 | Flight time: 68.6 hours | | | | Impacted on moon: closeup photographic experiment returned 4316 high quality photographs in last 13 minutes |
| Cosmos 36 | 1964 42A | USSR | July 30, 1964 | Kapustin Yar | | | 91.9<br>91.5 | 161<br>156 | 313<br>278 | 49<br>49.0 | In orbit: unannounced payload |
| None | 1964 43A | USAF | Aug 5, 1964 | WTR | TAT-Agena D | | 90.7 | 271 | 4076 | 80.0 | Decayed August 31, 1964: classified payload |
| Cosmos 37 | 1964 44A | USSR | Aug 14, 1964 | Tyuratam | | | 89.5 | 127 | 186 | 65 | Re-entered or decayed August 22, 1964: unannounced payload |
| None | 1964 45A | USAF | Aug 14, 1964 | WTR | Atlas-Agena D | | 89.0 | 93 | 191 | 95.5 | Decayed September 23, 1964: classified payload (initial orbital data as of August 15, 1964) |
| None | 1964 45B | | | | | | 127.4<br>127.4 | 163<br>162 | 2332<br>2334 | 95.6<br>95.7 | In orbit: classified payload |
| Cosmos 38 | 1964 46A | USSR | Aug 19, 1964 | | | | 95.2<br>91.3 | 130<br>122 | 544<br>295 | 56.2<br>56.1 | In orbit: unannounced payload, first Soviet triple payload launch |
| Cosmos 39 | 1964 46B | | | | | | 95.2<br>92.0 | 130<br>122 | 544<br>325 | 56.2<br>56.1 | In orbit: unannounced payload |
| Cosmos 40 | 1964 46C | | | | | | 95.2<br>91.6 | 130<br>125 | 544<br>306 | 56.2<br>56.1 | In orbit: unannounced payload |
| Syncom 3 | 1964 47A | NASA (GSFC) | Aug 19, 1964 | WTR | TAD | 86 | 1436.2<br>1436.0 | 22,164<br>22,146 | 22,312<br>22,324 | 1.0<br>1.0 | In orbit: first truly synchronous comsat, now stationed at 180° W longitude, communication tests successful |

Period: minutes
Perigee and Apogee: statute
Inclination: degrees from the

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| None | 1964 48A | USAF | Aug 21, 1964 | WTR | TAT-Agena D | | 91.6<br>91.2 | 217<br>203 | 226<br>211 | 115.0<br>115.0 | In orbit: classified payload (initial orbital data as of August 22, 1964) |
| Cosmos 41 | 1964 49D | USSR | Aug 22, 1964 | Tyuratam | | | 715<br>714.6 | 245<br>272 | 24,765<br>24,708 | 64<br>65.1 | In orbit: unannounced payload |
| Cosmos 42 | 1964 50A | USSR | Aug 22, 1964 | Kapustin Yar | | | 97.8<br>97.6 | 144<br>142 | 683<br>654 | 49<br>49.0 | In orbit: unannounced payload, first double payload launch in Cosmos program |
| Cosmos 43 | 1964 50C | | | | | | 97.8<br>97.5 | 144<br>142 | 683<br>650 | 49<br>49.0 | In orbit: unannounced payload |
| Explorer 20 | 1964 51A | NASA (GSFC) | Aug 25, 1964 | WTR | Scout | 97 | 103.9<br>103.9 | 540<br>541 | 634<br>634 | 79.9<br>79.9 | In orbit: ionosphere research satellite, part of Topside Sounder program, transmitting on 136.680, 136.350 mc |
| Nimbus 1 | 1964 52A | NASA (GSFC) | Aug 28, 1964 | WTR | Thor-Agena B | 830 | 98.3<br>98.4 | 263<br>266 | 579<br>582 | 98.6<br>98.7 | In orbit: second-generation weather satellite, 27,000 photos returned until August 28, 1964 when solar paddles locked |
| Cosmos 44 | 1964 53A | USSR | Aug 29, 1964 | Kapustin Yar | | | 99.5<br>99.5 | 384<br>378 | 534<br>537 | 65<br>65.1 | In orbit: unannounced payload |
| OGO 1 | 1964 54A | NASA (GSFC) | Sept 4, 1964 | ETR | Atlas-Agena B | 1,073 | 64.0 hrs<br>63.9 hrs | 175<br>245 | 92,827<br>94,457 | 31.1<br>31.2 | In orbit: spin-stabilized rather than earth-oriented, returning good data from 16 of 20 geophysical experiments |
| Cosmos 45 | 1964 55A | USSR | Sept 13, 1964 | Tyuratam | | | 90 | 128 | 203 | 65 | Re-entered or decayed September 18, 1964: unannounced payload |
| None | 1964 56A | USAF | Sept 14, 1964 | WTR | TAT-Agena D | | 90.8 | 119 | 286 | 85.0 | Decayed October 6, 1964: classified payload (initial orbital data as of September 15, 1964) |

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Period: minutes
Perigee and Apogee: statute miles
Inclination: degrees from the equator

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# INTERNATIONAL LOG OF SPACE LAUNCHES◆ (CONTD)

| NAME | INT'L DESIG. | PROJECT DIRECTION | LAUNCH DATA | | | WT. | INITIAL CURRENT ORBITAL DATA | | | | RESULTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date | Site | Vehicle | | Period | Perigee | Apogee | Incl. | |
| Saturn SA-7 | 1964 57A | NASA | Sept 18, 1964 | ETR | Saturn I | 36,700 | 88.4 | 114 | 141 | 31.7 | Decayed September 22, 1964: unmanned Apollo boiler plate command, service modules orbited attached to S-IV second stage |
| None | 1964 58A | USAF | Sept 23, 1964 | WTR | Atlas-Agena D | | | | | | Decayed September 28, 1964: classified payload |
| Cosmos 46 | 1964 59A | USSR | Sept 24, 1964 | | | | 89.2 | 134 | 168 | 50.3 | Re-entered or decayed October 2, 1964: unannounced payload |
| Explorer 21 | 1964 60A | NASA (GSFC) | Oct 3, 1964 | ETR | Delta | 136 | 35 hrs<br>35.0 hrs | 122<br>119 | 59,253<br>59,397 | 33.5<br>33.5 | In orbit: second IMP, apogee much lower than planned 126,500 miles, transmitting on 136.145 mc |
| None | 1964 61A | USAF | Oct 5, 1964 | WTR | TAT-Agena D | | 90.4 | 109 | 243 | 80.0 | In orbit: classified payload |
| Cosmos 47 | 1964 62A | USSR | Oct 6, 1964 | Tyuratam | | | 90.0 | 110 | 257 | 64.8 | Re-entered or decayed October 7, 1964: unannounced payload |
| None<br>None<br>None | 1964 63B<br>1964 63C<br>1964 63E | USAF/USN | Oct 6, 1964 | WTR | Thor-Able Star | | 106.6<br>106.6<br>106.6 | 657<br>655<br>657 | 673<br>674<br>673 | 89.9<br>89.9<br>90.0 | In orbit: classified payload<br>In orbit: classified payload<br>In orbit: classified payload |
| None | None | USAF | Oct 8, 1964 | WTR | Atlas-Agena D | | — | — | — | — | Failed to orbit: classified payload |
| Explorer 22 | 1964 64A | NASA (GSFC) | Oct 9, 1964 | WTR | Scout | 116 | 104.7<br>104.8 | 549<br>551 | 669<br>672 | 79.7<br>79.7 | In orbit: ionosphere and geodetic research satellite, being tracked by laser, transmitting on 136.170 mc |
| Voskhod 1 | 1964 65A | USSR | Oct 12, 1964 | Tyuratam | | | 90.1 | 100 | 255 | 65 | Re-entered October 12, 1964: first three-man crew – V. Komarov, K. Feoktistov and B. Yegorov, landed after 16 orbits |
| Cosmos 48 | 1964 66A | USSR | Oct 14, 1964 | Tyuratam | | | 89.4<br>89.4 | 122<br>129 | 177<br>163 | 65<br>65.0 | In orbit: unannounced payload |

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